Using cereal to increase dietary fiber intake to the recommended level and the effect of fiber on bowel function in healthy persons consuming North American diets1–3

Vladimir Vuksan, Alexandra L. Jenkins, David JA Jenkins, Alexander L. Rogovik, John L. Sievenpiper, and Elena Jovanovski

ABSTRACT

Background: Dietary fiber intake remains low despite increasing evidence for its health benefits, including laxation.

Objective: We aimed to assess the effects of increasing fiber intake on bowel habits and gastrointestinal tolerance in healthy persons consuming a typical Canadian or US diet.

Design: Under a randomized crossover design, 23 free-living participants consumed a typical Canadian or US diet (35% fat, 12 g fiber/d) and received 25.0–28.7 g fiber/d from each of 5 breakfast cereals: All-Bran (AB), Bran Buds with Corn (BBC), Bran Buds with Psyllium (BBP), BBC with viscous fiber blend (VFB), or a low-fiber control for 3 wk, with each study arm separated by a washout of ≥1 wk. Seven-day stool collections and a symptom diary were obtained during the last week of each study arm.

Results: All study cereals induced significant (P < 0.05) increases in fecal bulk from the control diet at 128 ± 38 g to 199 ± 56, 199 ± 57, 247 ± 87, and 197 ± 63 g with consumption of AB, BBC, BBP, and VFB, respectively; less intestinal transit time; and significantly (P < 0.05) greater bowel movement frequency. Despite the increased activity of the bowel, a positive level of comfort was maintained. BBP was more effective than other cereals in terms of increasing fecal wet weight (P < 0.05).

Conclusion: Water-insoluble dietary fibers (ie, AB and BBC) and their mixtures with water-soluble fibers (ie, BBP and VFB) in the form of breakfast cereals (2.5 servings/d) proved to be a practical way of increasing fiber intake to recommended levels, while maintaining a good level of tolerance.

INTRODUCTION

Dietary fibers have important physiologic properties and should be consumed in adequate quantities. The Dietary Reference Intakes (1) and Dietary Guidelines for Americans (2) recommend a daily dietary fiber intake of 14 g/1000 calories consumed. However, the average consumption within the typical Western diet is less than one-half of that recommended intake, an amount that has not changed over the last 2 decades (3, 4). Substantial dietary changes are required to meet estimated needs, and one possible approach could be the use of fiber supplements (1).

Despite the broad range of potential health applications attributed to dietary fiber, including the treatment of colonic disorders (5) and the association of dietary fiber with a lower risk of heart disease (6, 7), diabetes (8), and colon cancer (9), the ideal types of fiber and the proportions in which they should be fed are still not clearly defined. The water-insoluble forms of fiber, such as wheat bran, have been advocated for their effects in promoting colonic mucosal health by causing various changes in bowel function, such as increasing fecal bulking or reducing transit time through the gut. Conversely, the water-soluble or viscous dietary fiber is commonly believed to be more influential at a metabolic level, by decreasing the blood cholesterol or glucose concentration. Thus far, in terms of bowel function and side effects, abundant information has been gathered for water-insoluble fibers, mainly wheat bran, but little information exists for the water-soluble forms. It was shown in the past few years that water-soluble fibers (glucomannan and psyllium) also function extensively in the large colon to promote laxative effects and consequently to promote metabolic benefits (10, 11). Most previous studies focused primarily on one or the other form of fiber (12, 13, 14), and thus we felt that different types of fiber in a form in which most fiber is consumed warranted further assessment. Moreover, an increase in dietary fiber intake to the recommended level, which averages more than double the amount currently consumed, is of concern to most people because of negative gastrointestinal effects, such as flatulence, abdominal discomfort, and diarrhea.

The present study investigated a combination of water-insoluble (wheat and corn) and -soluble [psyllium and a viscous fiber blend (VFB) containing glucomannan and xanthan fibers consumed in breakfast cereal with respect to the fibers’ ability to induce changes in bowel habits, including fecal bulk, defection frequency, and transit time and to the gastrointestinal side effects measured by a symptom diary in healthy persons consuming a typical Canadian or US diet. The test fibers in this study were
provided in the recommended amounts for the general population and combined in the form of different breakfast cereals; breakfast cereals are a source of dietary fiber whose health properties and practicality have been well established for many decades.

**SUBJECTS AND METHODS**

**Subjects**

Subjects were recruited by advertisement and telephone or personal interview. The study initially enrolled 25 subjects. Two participants dropped out at the first treatment period for reasons not related to the study interventions (e.g., conflicting schedule), and they were not included in the data assessment. The remaining 23 persons (12 M, 11 F) aged 35 and they were not included in the data assessment. The remaining participants dropped out at the first treatment period for reasons personal interview. The study initially enrolled 25 subjects. Two subjects cades.

The inclusion criteria were self-reported ≥3 bowel movements per week with wet fecal output >50 g/d. Subjects were advised to eat a typical Canadian or US diet. Persons following a special diet, such as a vegetarian diet, and those with gastrointestinal disorders, bowel abnormalities, or a major illness were excluded, as were subjects using laxatives, diuretics, antidepressants, codeine, or antibiotics. Subjects were advised to consume >50% of any of the study supplements; changes of body weight of no more than ±2 kg/mo during the study were requested.

Assuming that the average wet fecal output among healthy subjects consuming the low-fiber cereals is on the order of 120 g/d (15, 16) and that the addition of 1 g wheat bran/d to the control diet increases fecal output by an average of 2.5 to 3.0 g/d (16), we calculated that the supplementation of ≥20 g of a test fiber would increase fecal output from 120 g/d to ≥170 g/d. Assuming an SD of 70 g/d (16), a sample size of 16 subjects is needed to ensure an 80% chance of correctly identifying a difference between the test and control means at an 0.05 level of significance. We further revised this sample size upwardly to improve the power of the study.

Written informed consent was obtained from all participants. The study was approved by the University of Toronto Committee for the Use of Human Subjects in Research and was carried out at the University of Toronto and St Michael’s Hospital.

**Experimental design**

A 5-phase randomized crossover design was used, in which all subjects took each treatment and acted as his or her own control. Each treatment phase was 21 d in duration and was followed by a washout phase of ≥7 d. The first 10 d of each treatment phase, designated as the habitual period, consisted of the consumption of a test cereal in conjunction with the participant’s typical diet; during the latter 11 d, or metabolic period, each participant continued to consume the test cereal, but a metabolic diet was supplemented to replace his or her habitual food.

**Dietary record and symptom diary**

Before the experimental portion of the study, a screening period of 7 d was designed to establish the subjects’ baseline to ensure that candidates met all inclusion criteria. During this period, dietary records and symptom diaries of all participants were monitored. These records involved descriptions of the types and quantities of foods consumed by the participants. A weighing scale was provided to the subjects to aid in the measurement of food quantity. Participants were not asked to discontinue including any foods in their diet. During each of the experimental phases, 3 assigned days of food records were collected during the habitual period. Dietary intake for both the 7-d baseline and 3-d habitual periods were analyzed by using the University of Toronto Nutriput Diet Analysis Program based on the US Department of Agriculture Handbook # 8 Series for energy and nutrient information (Internet: http://www.nal.usda.gov/fnic/foodcomp/search/). Missing fiber values were added by using data from the Minnesota Database (Internet: http://www.ncc.umn.edu/products/database.html). When a difference in carbohydrate was observed between the 2 databases, a ratio was used to adjust the fiber value. The form and duration of habitual physical activity were recorded by the dietitian. If a participant regularly performed exercise, he or she was instructed to maintain the pattern for the entire study. Furthermore, any symptoms related to bowel habits, unusual sensations, or both were also noted. Symptom diaries used a 5-point scale and included flatus (1, no gas; 5, extreme flatulence), bloating (1, no bloating; 5, extreme bloating), stool consistency (1, watery; 5, hard), ease of movement (1, easy; 5, hard), and abdominal pain (1, no pain; 5, extreme pain). The scale was designed to describe the qualitative observations of the participants regarding their gastrointestinal and bowel sensations. Any unusual stresses were noted, because psychological and emotional factors may affect defecation. Body weight was measured at each visit to the research center.

**Diet and test cereals**

The study involved the investigation of 4 different types of fibers given in the form of breakfast cereals. The test fibers included 4 high-fiber cereals—All-Bran (AB), Bran Buds with Corn (BBC), and Bran Buds with Psyllium (BBP) (all: Kellogg Company, Battle Creek, MI), and BBC plus a VFB—and a low-fiber control. VFB is a proprietary fiber blend (patented combination, US patent 7 326 404; Internet:http://www.uspto.gov/web/patents/patog/week06/OG/html/1327-1/US07326404-20080205.html) with a characteristic, highly viscous polysaccharide. Viscosity of the VFB was estimated to be 700 poise, as measured with a viscometer (RVT; DW Brookfield Ltd, Cooksville, Canada) at a concentration of 1% and a shear rate of 1/30 s with a spindle type F. The total fiber content in VFB is 95% (70% glucomannan and 30% xanthan), and 98% of the fiber is water soluble.

The content (%) of raw wheat bran, corn bran, psyllium, and VFB in the cereals is shown in Table 1. All cereals were prepared with the use of the same milling process, and they did not differ significantly in particle size. The cereals were provided in portions of 58–87 g (≈2.5 servings/d) depending on the fiber content. The aim was to provide 25.0–28.7 g total dietary fiber (TDF)/d from cereals in addition to ≈12 g fiber/d from the metabolite diet, proportional to caloric intake.

During the habitual period of each experimental phase, subjects consumed their usual diet, which coincides with a typical North American diet, and food records were monitored to maintain consistency throughout all study periods. Foods in the metabolic period were portioned and packaged on a weekly basis and then sent by courier to the participants. Foods provided included a piece of toast with cheddar cheese or ham for lunch; dinner included a choice of pasta with minced meat, mashed potatoes with steak, or hamburger with French fries. Additional food
servings during the day also included dairy (ie, milk or yogurt), fruit and vegetables, and beverages (tea or coffee). Returned food and the experimental breakfast cereals were weighed and used to determine compliance. A food scale was provided for all subjects to assist in exact portion size measurement for items such as fruit and vegetables that could not be prepared beforehand. So that all diets for a given participant would be as similar as possible, any dietary changes occurring in phase 1 were duplicated in the food delivered for the subsequent 4 phases.

The metabolic diet was typical of a Canadian or US diet in terms of both nutrient profile and types of food provided; it was similar in energy level and included a 3-d rotation of foods. The target nutrient profile for the metabolic diet was approximately 15% protein, 35% fat, and 50% carbohydrates. Foods containing seed or thick skins were minimized to avoid obscuring the transit time measurements. Energy levels were individualized according to caloric intake (2000, 2500, 3000, or 3500 kcal) to promote weight maintenance and, subsequently, adherence to the diet. Because subjects varied in ethnic background, individual food preferences were accommodated where possible. Beverages such as coffee, tea, and alcohol were allowed in moderation, but participants were asked to set patterns for the entire study period and were told of the importance of not deviating from this pattern.

During all but one metabolic period, each subject consumed a standard of 105:75 ppm (hydrogen/methane) (Linde Canada, Guelph, Canada) on a digital electronic scale (PJ6000; Mettler-Toledo Inc, Columbus, OH) that was accurate to 0.1 g. Fecal dry matter content was established after the stools were freeze-dried with the use of the Labconco system (Labconco Corp, Kansas City, MO) for 48 h. The Mettler digital scale was used to determine the weight before and after freeze-drying. A standard of 105:75 ppm (hydrogen/methane) (Linde Canada, Guelph, Canada) was used before and after the analysis of each breath sample.

Determination of breath hydrogen (H$_2$) and methane (CH$_4$) gases was conducted on day 21 of each experimental phase. The breath sample collection was to begin before breakfast and then was conducted hourly for 12 h. Breath samples were collected in Haldane-Priestley tubes and stored at $-20^\circ$C immediately after collection. Within 2 d, the breath samples were analyzed by gas chromatography (model DP; Quinton Microlyzer, Milwaukee, WI). A standard of 105:75 ppm (hydrogen/methane) (Linde Canada, Guelph, Canada) was used before and after the analysis of each breath sample.

To determine intestinal transit time, radiopaque barium–impregnated polyethylene pellets (Sitzmarks; Konsyl Pharmaceuticals Inc, Fort Worth, TX) encased in gelatin capsules (24 pellets/capsule) were assigned to the subjects. Participants consumed the capsules at breakfast on the first, second, and third days of the 7-d stool collection period. All fecal samples were X-rayed to ascertain the passing of the pellets. Transit time was calculated as the mean time needed for the first 80% of the pellets to be passed in the stool (17).

### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>AB</th>
<th>BBC</th>
<th>BBP</th>
<th>VFB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal consumed (g/d)</td>
<td>38 ± 8</td>
<td>85 ± 17</td>
<td>63 ± 13</td>
<td>69 ± 14</td>
<td>55 ± 11</td>
</tr>
<tr>
<td>Energy and macronutrients from the cereals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (kcal/d)</td>
<td>140 ± 28</td>
<td>209 ± 42</td>
<td>133 ± 27</td>
<td>149 ± 30</td>
<td>117 ± 23</td>
</tr>
<tr>
<td>Protein (g/d)</td>
<td>3.3 ± 0.7</td>
<td>11.0 ± 2.2</td>
<td>6.2 ± 1.2</td>
<td>6.3 ± 1.3</td>
<td>5.5 ± 1.1</td>
</tr>
<tr>
<td>Fat (g/d)</td>
<td>0.3 ± 0.4</td>
<td>1.9 ± 0.4</td>
<td>1.2 ± 0.2</td>
<td>0.8 ± 0.2</td>
<td>1.0 ± 0.2</td>
</tr>
<tr>
<td>Available carbohydrate (g/d)</td>
<td>31.5 ± 6.3</td>
<td>36.8 ± 7.4</td>
<td>24.5 ± 4.9</td>
<td>29.0 ± 5.8</td>
<td>21.4 ± 4.3</td>
</tr>
<tr>
<td>Total fiber (g/d)</td>
<td>1.3 ± 0.3</td>
<td>28.7 ± 5.7</td>
<td>25.0 ± 5.0</td>
<td>28.6 ± 5.7</td>
<td>26.7 ± 5.3</td>
</tr>
<tr>
<td>Soluble fiber (g/d)</td>
<td>0.4 ± 0.4</td>
<td>2.0 ± 0.4</td>
<td>1.4 ± 0.3</td>
<td>6.7 ± 1.3</td>
<td>6.1 ± 1.2</td>
</tr>
<tr>
<td>Insoluble fiber (g/d)</td>
<td>1.3 ± 0.3</td>
<td>26.7 ± 5.3</td>
<td>23.5 ± 4.7</td>
<td>21.9 ± 4.4</td>
<td>20.7 ± 4.1</td>
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<tr>
<td>Fiber ingredients</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat bran (%)</td>
<td>0 ± 0</td>
<td>77 ± 1</td>
<td>51 ± 1</td>
<td>51 ± 1</td>
<td>51 ± 1</td>
</tr>
<tr>
<td>Corn bran (%)</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>22 ± 1</td>
<td>8 ± 1</td>
<td>22 ± 1</td>
</tr>
<tr>
<td>Psyllium (%)</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>13 ± 1</td>
<td>0 ± 0</td>
</tr>
<tr>
<td>VFB (%)</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>9.4 ± 0.4</td>
</tr>
</tbody>
</table>

1. AB, All-Bran; BBC, Bran Buds with Corn; BBP, Bran Buds with Psyllium (all: Kellogg Company, Battle Creek, MI); VFB, BBC with viscous fiber blend. Significant ($P < 0.05$) differences were observed between the treatments in the amount of cereal consumed and energy and macronutrient intakes (Friedman test). Because of a high level of viscosity, VFB was sprinkled on the cereal to avoid congealing.

2. $x \pm SD$ (all such values).
Statistical analysis

The results are presented as means ± SDs for parametric data and as medians (interquartile ranges) for non-Gaussian distributions. The primary outcome measured was the average daily fecal wet weight expressed as a total fecal wet weight divided by the number of days of collection. Daily fecal dry weight, intestinal transit time, and frequency of defecation were reported and evaluated as secondary variables, which acted as validity checks. Breath gas analyses also were conducted. Parametric analyses were conducted after a comparison of the sampling distribution to a normal distribution (Shapiro-Wilk and Kolmogorov-Smirnov tests). The tests did not reject the null hypothesis at α = 0.05. Statistical analysis was undertaken with SAS (version 8.02; SAS Institute Inc, Cary, NC) and SPSS (version 15.0; SPSS Inc, Chicago, IL) software. The mixed model adjusted for age, sex, and caloric intake, and the post hoc Tukey-Kramer comparison test was used to compare different diets. All comparisons were paired, and thus each subject served as his or her own control. For nonnormally distributed data, a global comparison was performed by using the nonparametric Friedman test, taking repetition into account, and with, if the test was significant, subsequent paired comparisons with the control diet by using Wilcoxon’s signed-ranks test. Data were considered significant at P < 0.05.

Comparisons between the baseline and control diets were performed by using the paired t test for parametric distributions and Wilcoxon’s signed-ranks test for non-Gaussian distributions.

RESULTS

Metabolic diets and breakfast cereals

Subject compliance with respect to the metabolic diet was high: ≥97% of food and 89–97% of cereals delivered were consumed. The composition of the experimental cereals and the amounts of cereals consumed are shown in Table 1. Because the cereals were matched for quantity of TDF, significant (P < 0.05) between-cereal differences were observed in the amount of cereal consumed and the energy and macronutrient intakes. However, these differences were compensated for by the metabolic diet, and daily energy and macronutrient intakes did not differ significantly, except for a lower amount of TDF from the control diet (Table 2).

In terms of soluble dietary fiber, the main difference among the experimental cereals was the 13% of psyllium in BBP cereals and the 9.4% of viscous polysaccharide blend in VFB cereals. The reason for adding =35% less VFB than psyllium fiber was VFB’s very high level of viscosity, which would cause gelled clumps that make cereals less palatable. However, despite the fact that a smaller quantity of VFB was given, subjects still reported that some of the VFB, as much as ≈10%, remained on the side of the bowl.

The control diet did not differ significantly from each participant’s habitual diet in terms of fecal bulking and other variables (Table 3). This finding indicated that the addition of a control cereal to the diet was not a confounding factor and that any changes observed among the high-fiber cereal phases are most likely the effect of the fiber content in AB, BBC, BBP and VFB.

Subjects’ physical profile

Twenty-five subjects were enrolled in the study. The final analysis included 23 healthy persons (12 M, 11 F; 35 ± 12 y old; weight: 70 ± 15 kg; BMI: 23.8 ± 4.6; stool frequency: 1 ± 0.4/d); 2 persons dropped out for reasons not related to the study interventions. Weight and BMI changes were insignificant among the different phases during the course of the study. Therefore, it would appear that the metabolic diet was able to meet each participant’s dietary requirements and that it did not act as a confounding factor within the study.

Fecal weight and intestinal transit time

Based on a 7-d fecal collection period, the mean fecal output of the control diet was 128 ± 38 g/d (Table 3). Test cereals resulted in a fecal weight increase of 71 g for AB and BBC, 69 g for VFB, and 119 g for BBP (Table 3). When fecal output was expressed as 1 g stool per 1 g dietary fiber added (increment above control), tested fibers gave an increase of 2.8 ± 1.8, 3.0 ± 2.1, 4.8 ± 2.7, and 2.9 ± 2.1 g in wet stool for AB, BBC, BBP, and VFB, respectively. The stool per each 1-g increase in fiber for BBP was significantly larger, by 60–71%, than that for other cereals. All test cereals produced a significantly higher fecal dry weight than did the low-fiber control; there were no significant differences among the 4 treatments. The percentage of dry matter did not differ significantly among the treatments—exception BBP, which was significantly lower than BBC (Table 3). Furthermore, BBC had the slowest transit time of all of the experimental cereals, although the difference was not statistically significant. In each test cereal phase, there were 4 energy intake levels. When fecal weights were adjusted for energy intake, the between-diet differences remained similar to those with unadjusted data (Table 3). When male-female differences in fecal

| TABLE 2
| Compliance: metabolic diet and body weight

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal/d)</td>
<td>2675 ± 499</td>
<td>2777 ± 504</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>15.6 ± 2.9</td>
<td>13.9 ± 1.0</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>34.6 ± 4.3</td>
<td>31.7 ± 1.4</td>
</tr>
<tr>
<td>Carbohydrate (%)</td>
<td>50.0 ± 5.8</td>
<td>52.4 ± 1.9</td>
</tr>
<tr>
<td>TDF (g/d)</td>
<td>18.6 ± 4.8</td>
<td>12.2 ± 7.2b</td>
</tr>
<tr>
<td>TDF (g/100 kcal)</td>
<td>0.70 ± 0.24</td>
<td>0.44 ± 0.1*</td>
</tr>
<tr>
<td>Body weight, day 21 (kg)</td>
<td>—</td>
<td>69.3 ± 15.1</td>
</tr>
</tbody>
</table>

Experimental cereals

<table>
<thead>
<tr>
<th>Experimental cereals</th>
<th>AB</th>
<th>BBC</th>
<th>BBP</th>
<th>VFB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal/d)</td>
<td>2838 ± 566</td>
<td>2711 ± 485</td>
<td>2799 ± 533</td>
<td>2744 ± 523</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>14.6 ± 1.0</td>
<td>14.3 ± 1.0</td>
<td>14.1 ± 1.0</td>
<td>14.2 ± 1.0</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>31.4 ± 1.4</td>
<td>32.3 ± 1.4</td>
<td>31.8 ± 1.4</td>
<td>33.2 ± 1.9</td>
</tr>
<tr>
<td>Carbohydrate (%)</td>
<td>53.1 ± 1.4</td>
<td>51.9 ± 1.9</td>
<td>52.3 ± 1.9</td>
<td>51.7 ± 1.4</td>
</tr>
<tr>
<td>TDF (g/d)</td>
<td>38.8 ± 12.6b</td>
<td>37.5 ± 13.4b</td>
<td>39.8 ± 11.5b</td>
<td>38.3 ± 12.5b</td>
</tr>
<tr>
<td>TDF (g/100 kcal)</td>
<td>1.37 ± 0.05b</td>
<td>1.38 ± 0.05b</td>
<td>1.42 ± 0.1b</td>
<td>1.40 ± 0.1b</td>
</tr>
<tr>
<td>Body weight, day 21 (kg)</td>
<td>69.6 ± 15.3</td>
<td>69.7 ± 15.9</td>
<td>69.8 ± 15.6</td>
<td>69.4 ± 15.2</td>
</tr>
</tbody>
</table>

1 All values are x ± SD. AB, All-Bran; BBC, Bran Buds with Corn; BBP, Bran Buds with Psyllium (all: Kellogg Company, Battle Creek, MI); VFB, BBC with viscous fiber blend; TDF, total dietary fiber. Means in a row with different superscript letters are significantly different, P < 0.05.
Breath gases

Control breath hydrogen displayed low concentrations of H\(_2\); the median concentration was 8.0 ppm (interquartile range: 4.2–19 ppm). The AB and VFB test cereals significantly (by \(\approx 6\) ppm) increased the median breath H\(_2\) above control concentrations, whereas BBP did not cause an elevation of breath H\(_2\) (Table 3).

Nonparametric analysis of methane gas data included all subjects, whether they were methane producers or not. The median breath CH\(_4\) concentration was significantly lower with the AB and VFB test cereals than with the control cereal (Table 3).

### Breath gases

Despite the increased defecation frequency, larger stool size, and greater hydrogen production, a positive level of comfort was maintained in terms of the bowel movement symptoms, including ease of movement, stool consistency, and abdominal pain, which were similar to the control diet for all tested cereals (Table 4). Whereas stool consistency and ease of defecation remained primarily unchanged, a trend of softer stools and more rapid defecation was reported by some subjects. Although the symptoms of flatulence and bloating were somewhat increased, all of these variables were recorded at a level indicative of comfort and were in the lower range of the given scale.

### TABLE 3

Influence of different fiber sources on bowel habits and colonic health

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline(^1)</th>
<th>Control</th>
<th>AB</th>
<th>BBC</th>
<th>BBP</th>
<th>VFB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal wet weight (g/d)</td>
<td>127 ± 57.5(^a)</td>
<td>128 ± 58.4(^a)</td>
<td>199 ± 56.4(^b)</td>
<td>199 ± 56.7(^b)</td>
<td>247 ± 87.0(^b)</td>
<td>197 ± 63.2(^b)</td>
</tr>
<tr>
<td>Fecal wet weight (g/g fiber/d)</td>
<td>—</td>
<td>—</td>
<td>2.84 ± 1.8(^a)</td>
<td>3.01 ± 2.07(^a)</td>
<td>4.77 ± 2.7(^b)</td>
<td>2.87 ± 2.1(^a)</td>
</tr>
<tr>
<td>Fecal dry weight (g/d)</td>
<td>28.3 ± 12.3</td>
<td>28.3 ± 8.17(^a)</td>
<td>43.7 ± 11.7(^b)</td>
<td>48.5 ± 14.7(^b)</td>
<td>50.4 ± 14.9(^b)</td>
<td>43.2 ± 13.0(^b)</td>
</tr>
<tr>
<td>Dry matter (%)</td>
<td>23.0 ± 4.46</td>
<td>22.6 ± 3.80(^b)</td>
<td>22.2 ± 2.06(^a)</td>
<td>24.4 ± 2.43(^a)</td>
<td>20.9 ± 2.22(^b)</td>
<td>22.4 ± 3.43(^a)</td>
</tr>
<tr>
<td>Adjusted fecal wet weight (g/100 kcal/d)</td>
<td>4.75 ± 2.05</td>
<td>4.77 ± 1.37(^a)</td>
<td>7.44 ± 1.88(^b)</td>
<td>7.45 ± 1.98(^b)</td>
<td>9.21 ± 3.04(^b)</td>
<td>7.44 ± 2.33(^b)</td>
</tr>
<tr>
<td>Adjusted fecal dry weight (g/100 kcal/d)</td>
<td>1.05 ± 0.40</td>
<td>1.05 ± 0.27(^a)</td>
<td>1.64 ± 0.36(^b)</td>
<td>1.81 ± 0.48(^b)</td>
<td>1.88 ± 0.47(^b)</td>
<td>1.62 ± 0.45(^b)</td>
</tr>
</tbody>
</table>

\(^1\) AB, All-Bran; BBC, Bran Buds with Corn; BBP, Bran Buds with Psyllium (all: Kellogg Company, Battle Creek, MI); VFB, BBC with viscous fiber blend.

### TABLE 4

Bowel habits and defecation symptoms

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control</th>
<th>AB</th>
<th>BBC</th>
<th>BBP</th>
<th>VFB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intestinal transit time (h)</td>
<td>41.0 ± 18.9(^a)</td>
<td>29.1 ± 9.64</td>
<td>34.2 ± 16.8</td>
<td>30.9 ± 17.9</td>
<td>29.1 ± 10.2</td>
</tr>
<tr>
<td>Median (h)</td>
<td>32.3 (29.7–45.8)(^a)</td>
<td>27.8 (19.8–35.9)(^a)</td>
<td>27.2 (23.7–36.3)(^a)</td>
<td>24.9 (16.0–37.0)</td>
<td>25.4 (21.2–36.2)(^a)</td>
</tr>
<tr>
<td>Frequency (stools/d)</td>
<td>0.97 ± 0.25(^a)</td>
<td>1.17 ± 0.37(^b)</td>
<td>1.20 ± 0.41(^b)</td>
<td>1.27 ± 0.53(^b)</td>
<td>1.24 ± 0.42(^b)</td>
</tr>
</tbody>
</table>

\(^a\) x ± SD (all such values).

\(^b\) Median; interquartile range in parentheses (all such values).

\(^1\) AB, All-Bran; BBC, Bran Buds with Corn; BBP, Bran Buds with Psyllium (all: Kellogg Company, Battle Creek, MI); VFB, BBC with viscous fiber blend.

\(^2\) Baseline diet was not included in the ANOVA. Comparison between the baseline and control diets was performed by using the paired t test for parametric distributions and Wilcoxon’s signed-ranks test for non-Gaussian distributions.

\(^3\) Table is printed with different superscript letters, which are significantly different, \(P < 0.05\) (mixed model adjusted for age, sex, and caloric intake with Tukey-Kramer post hoc test for normal distributions; Friedman test and Wilcoxon’s signed-ranks test for nonnormally distributed data).

\(^4\) Significantly different from control, \(P < 0.05\) (Wilcoxon’s signed-ranks test).

\(^5\) Values on a unipolar 5-point ordinal scale.
Medical records and symptom diaries showed that 6 subjects had a feeling of urgency to defecate during the BBP study arm. This symptom may be the result of the significantly higher fecal weight and greater moisture concentration during that study arm (Table 3).

DISCUSSION

The present study showed, in a crossover, head-to-head comparison, that the addition of high-fiber cereals to a typical Canadian or US diet is a practical, efficacious, and safe way of increasing fiber intake from the current low levels to recommended levels. Cereal sources of both insoluble (12, 18) and soluble (psyllium, glucomannan, and xanthan) fibers induced an increase in fecal weight and frequency of defecation, which contributed to a positive comfort level. The psyllium added to wheat and corn bran fiber was shown to be more effective than were the other fibers in promoting bowel habits.

The average fecal output among healthy persons consuming the low-fiber cereals was 128 g/d, which is an average fecal weight in Canada or the United States (15, 16, 18). Undigested fiber, retention of water (13, 19), and the mechanical action of fiber (20) are responsible for much of the increase in fecal weight with high-fiber cereal consumption, as is illustrated by significantly greater increases in both wet and dry fecal weights with consumption of all test cereals than with consumption of the control cereal. BBC cereal, in which 22% of AB was replaced with corn bran, did not result in a change of fecal weight from AB, which suggests that the fecal bulking ability of corn bran matches that of AB.

The increase of 2.8 g stool/g additional dietary fiber in the control diet, as compared with AB, is consistent with findings in some other studies using wheat bran (12, 15, 16, 18). Cummings (13) included a table of the average increase in fecal output per 1 g fiber fed for wheat, this was 5.4 g; for corn, it was 3.3 g; and for psyllium, it was 4.0 g. The lower value in the present study for AB (2.8 g/g fiber) could indicate an effect of processing on the bran, because many of the studies summarized by Cummings used unprocessed wheat bran. At the same time, the laxative effect of BBP was surprisingly high in the present study, with almost 5 g feces/g added dietary fiber. Because the fecal weight was significantly higher with psyllium than with other cereals and because the fecal dry weight was similar in all cereals, the increase in fecal wet mass with BBP is likely to be due to moisture. Psyllium has the ability to form a gel matrix that binds water on the external surfaces of fiber particles, thus increasing the moisture content of the stool (10).

Both insoluble and soluble types of fiber may be fermentable by intestinal microflora, but soluble fiber usually has a higher fermentability (13). An increase in fermentation was shown in our study by an increase in flatulence and bloating, indicating a possibly higher level of microflora activity that was illustrated by increases in breath hydrogen and decreases in breath methane with AB, BBC, and VFB. Whereas hydrogen adds to the colonic bulk (13), methane appears to slow intestinal transit by augmenting small-bowel contractile activity (21), and thus it provides an additional mechanism for the bulking effect. In addition, because a fiber-rich diet may lower the risk of colon cancer (4, 14, 22–24), lower CH₄ concentrations could be associated with the prevention of bowel malignancy (25, 26).

With the low hydrogen and high methane values recorded in the BBP phase, it would appear that fermentation of psyllium is either minimal (if any occurs) or appreciably slow. It has been shown that a gel-forming fraction of psyllium escapes microbial fermentation (10). Wolfer et al (27) also reported that psyllium had no effect on breath hydrogen, methane, or serum acetate concentrations. A slow production of H₂ introduces a stable environment for methanogenic bacteria that may use hydrogen for the generation of methane as quickly as it appears (27).

As expected, we found a reduction in intestinal transit time with consumption of the cereals, although all of the transit measurements were well within the normal range (repeated transit measurements in a person under rigid diet control vary by 20% to 30%). All cereals produced a transit time that was ≈30% shorter, except for BBC, which reduced transit time by 20% compared with the control. It is interesting that, despite greater fecal weight after consumption of BBC, the transit time was minimally improved. The explanation could be the percentage of dry matter with BBC that was higher than that with other experimental cereals and the positive correlation between these 2 variables.

The greater cereal fiber content induced significant increases in daily bowel movement. It was previously reported that the frequency of defecation is correlated with the size of the stool (28), and the improvements observed in the ease of passage and stool consistency were most likely the result of a higher moisture content in the feces.

Viscous fibers are therapeutically useful in modifying post-prandial hyperglycemia (29) and have been associated with alterations in serum cholesterol concentrations (30), prolonged gastric emptying, and slower transit time through the small intestine (31). It has been shown that physiologic efficacy of dietary fiber is the same whether fiber is incorporated in breakfast cereals or sprinkled on the cereal (32). Although many dietary fibers alter viscosity in the gastrointestinal tract (31), few data exist for a link between viscosity and laxation. Findings summarized by Cummings (13) and subsequently published research indicated that psyllium is a unique viscous fiber, and even its analysis as a soluble fiber requires special steps. Whereas the study of the effects of glucomannan on the large intestine (11) provided evidence that some fibers analyzed as a soluble may increase stool weight, many studies of other soluble fibers (eg, pectin or guar gum) have not supported a large-bowel effect. Therefore, the influence of fiber viscosity on laxation requires further study.

In conclusion, water-insoluble (AB and BBC) dietary fibers and their mixtures with water-soluble (BBP and VFB) fibers in the form of breakfast cereals (2.5 servings/d) proved to be a practical way of increasing fiber intake to recommended levels, and they induced an increase in fecal weight, decreased transit time, and improved bowel movement frequency with sustained gastrointestinal tolerance. Fiber can safely be consumed at twice the quantity of current intake with no change or little change in gastrointestinal symptoms. Combinations of insoluble fibers with psyllium have stronger bulking effects than do insoluble fibers alone.

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The authors’ contributions were as follows—VV: conceived of the project, wrote the protocol, obtained the funding, and contributed significantly to the manuscript; ALR: contributed to data analysis and manuscript preparation; DJAJ: contributed to the study design, data interpretation, and
REFERENCES


