

Viscosity rather than quantity of dietary fibre predicts cholesterol-lowering effect in healthy individuals

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Abstract

The well-documented lipid-lowering effects of fibre may be related to its viscosity, a phenomenon that has been understudied, especially when fibre is given against the background of a typical North American (NA) diet. In this three-arm experiment, we compared the lipid-lowering effect of low-viscosity wheat bran (WB), medium-viscosity psyllium (PSY) and a high-viscosity viscous fibre blend (VFB), as part of a fibre intervention aimed at increasing fibre intake to recommended levels within the context of a NA diet in apparently healthy individuals. Using a randomised cross-over design, twenty-three participants (twelve males and eleven females; age 35 (SD 12) years; LDL-cholesterol (C) 2.9 (SEM 0.6) mmol/l) consuming a typical NA diet received a standard, fibre-enriched cereal, where approximately one-third of the fibre was either a low-viscosity (570 centipoise (cP)) WB, medium-viscosity (14 300 cP) PSY or a high-viscosity (136 300 cP) novel VFB, for 3 weeks separated by washout periods of ≥ 2 weeks. There were no differences among the treatments in the amount of food consumed, total dietary fibre intake, reported physical activity and body weight. Final intake of the WB, PSY and VFB was 10.8, 9.0 and 5.1 g, respectively. Reduction in LDL-C was greater with the VFB compared with the medium-viscosity PSY (-12.6 (SEM 3.5) %, $P=0.002$) and low-viscosity WB (-14.6 (SEM 4.2) %, $P=0.003$). The magnitude of LDL-C reduction showed a positive association with fibre apparent viscosity ($r = 0.41$, $P=0.001$). Despite the smaller quantity consumed, the high-viscosity fibre lowered LDL-C to a greater extent than lower-viscosity fibres. These data support the inclusion of high-viscosity fibre in the diet to reduce plasma lipids among apparently healthy individuals consuming a typical NA diet.

Key words: Dietary fibre: Viscosity: Cereals: Blood lipids: Healthy subjects

CVD continues to be the leading cause of death in North America. One of the drivers of this CVD epidemic may be the typical North American (NA) diet characterised by high sugar, saturated fat and cholesterol intake, and low dietary fibre consumption. Based on numerous clinical studies, there is a modest but well-established cholesterol-lowering effect demonstrated with gel-forming viscous fibres⁽¹⁾. Furthermore, the cholesterol-lowering effect of fibre-rich foods, or their purified preparations, is dependent on their capacity to hydrate and increase the viscosity of human digesta⁽²⁾. It has not yet been shown whether the lipid-lowering effects of fibre can occur in conjunction with a typical high-saturated fat NA diet, and whether this effect is related to fibre viscosity rather than quantity alone.

In the present study, we assessed the lipid-lowering potential of three fibres: low-viscosity wheat bran (WB);

medium-viscosity psyllium (PSY); high-viscosity fibre blend (VFB). Both WB and PSY have been studied extensively. In 1998, the Food and Drug Administration permitted a health claim for CHD-lowering benefits of PSY.

VFB is a novel proprietary blend of glucomannan fibre and xanthan (US patent 7,326,404). To date, preliminary results suggest that VFB supplementation may result in marked improvements in metabolism, including lipid-lowering effects, in healthy subjects and individuals with the metabolic syndrome or type 2 diabetes^(3–5).

Thus, the objective of the present study was to explore the possibility of developing a novel dietary approach that is rooted in the recommendation to increase total fibre intake and capitalise on the effect of fibre viscosity. If shown to be effective, a simple and practical tool may be developed to

Abbreviations: C, cholesterol; NA, North American; PSY, psyllium; VFB, viscous fibre blend; WB, wheat bran.

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reduce plasma lipids among apparently healthy individuals consuming a NA diet.

Experimental methods

Subjects and study design

Methodology and the effects of the cereals on bowel function have been previously described in detail⁽⁶⁾. In brief, twenty-five healthy participants were recruited for the study that used a three-arm cross-over design in which each subject received all three treatments in random order. Each treatment phase was 21 d in duration, followed by a 2–3-week washout period. Fibre was added in the form of breakfast cereals or fibre sprinkle plus breakfast cereal to an otherwise typical NA diet. During each 21 d treatment phase, subjects consumed their usual diet for the first 9 d, and for the remaining 11 d, they received an individualised, 3 d rotating, metabolic diet, where foods were portioned and couriered to participants on a weekly basis. The target nutrient profile for the study diets was approximately 14–16% protein, 32–35% fat and 50–52% carbohydrates, including experimental cereals, which corresponds to a typical NA diet, and 14 g/4184 kJ dietary fibre. Returned food and experimental cereals, including VFB sprinkling material, were weighed and used to determine compliance.

The present study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the University of Toronto Committee for the Use of Human Subjects in Research, with written informed consent obtained from all subjects, and carried out at the Risk Factor Modification Centre at St Michael's (Toronto, ON, Canada).

Fibre treatments

The test fibres included All Bran as a source of WB (All Bran[®]; Kellogg Company, Battle Creek, MI, USA), Bran Buds (WB and maize bran) with PSY (Bran Buds[®] with PSY; Kellogg Company) or a VFB, sprinkled on wheat and maize bran cereals (Bran Buds[®]; Kellogg Company). The amount of total dietary fibre given per day (approximately 1.4 g/418.4 kJ consumed) was based on the Institute of Medicine recommendations and previous studies, providing 26.7–28.7 g of total dietary fibre daily from cereals in addition to approximately 12 g of fibre from the metabolic diet^(1,7). Cereals were provided in individual packages as a breakfast. The amount of the VFB given was half that of the other two fibres because of problems with palatability⁽⁶⁾.

The portion size of experimental cereals varied from 85 to 69 g (approximately 2.5 servings/d) depending on the type of fibre added, providing mean fibre quantities of 11.1 g/d of WB, 9.8 g/d of PSY and 5.7 g/d of VFB. Cereals were processed and prepared by the Kellogg Company. VFB is a proprietary blend (US patent 7,326,404), with the characteristics of highly viscous dietary fibre. It was developed and prepared in our Rheology laboratory at the Risk Factor Modification Centre.

Apparent viscosity of the test fibre solutions (centipoise) was measured at room temperature (21°C) in 1% fibre

solutions. The measurement was performed with Brookfield viscometer, model D (Brookfield Engineering Laboratories, Inc., Stoughton, MA, USA), using spindle F and shear rate/12, because the solutions were non-Newtonian.

Anthropometric and clinical measurements

Anthropometric measurements and blood samples were obtained on days 0, 9 and 21. Serum was stored at –70°C after collection and analysed at the end of the study for total cholesterol (C), TAG and HDL-C, which were measured enzymatically. LDL-C content was estimated using the formula of Friedewald. ApoA-1 and apoB were determined by rocket immunoelectrophoresis.

Power analysis

Assuming a standard deviation of LDL-C at 0.7 mmol/l and a decrease in the LDL-C concentration of 0.6 mmol/l with the addition of the VFB^(4,5), a sample size of twenty-two subjects was needed to ensure an 80% chance of correctly identifying a difference between test and control means at a 0.05 level of significance.

Statistical analysis

Results are presented as means and standard deviations or means with their standard errors. Statistical analysis was undertaken with SAS release 9.1 (SAS Institute, Inc., Cary, NC, USA) and SPSS release 17.0 (SPSS, Inc., Chicago, IL, USA). The mixed model adjusted for age, sex and energy intake with the *post hoc* Tukey–Kramer comparison test was used to compare changes in plasma lipid concentrations (on days 9 and 21) and their ratios among the treatments. For non-normally distributed data (amount of cereal consumed, energy and macronutrient intakes), a global comparison was performed using the non-parametric Friedman test, taking repetition into account. Differences were considered significant at $P < 0.05$. Linear regression analysis was used to determine dose–response relationships between viscosity level (poise), quantity of studied fibres (g/d) and change in LDL-C concentrations (mmol/l).

Results

Subject characteristics

The final analysis included twenty-three subjects (twelve males and eleven females) aged 35 (SD 12) years, BMI 23.8 (SD 4.6) kg/m² with mean total-C 4.8 (SEM 0.7) mmol/l and mean LDL-C 2.9 (SEM 0.6) mmol/l. Weight changes were not different between and within the different phases during the study. Blood pressure changes measured on day 21 were not significantly different in both within-group and between-group analyses (data not shown).

Treatments and compliance

Subject compliance was high with a mean intake of 97% of the food provided, 89–97% of the cereals and 89% of the

VFB sprinkle. Total intake of the WB, PSY and VFB was 10.8, 9.0 and 5.1 g fibre/d, respectively.

Viscosity

Average viscosity of 1% fibre solutions was 570, 14 300 and 136 300 centipoise for WB, PSY and VFB, respectively.

Gastrointestinal effects

Defecation frequency and stool size production increased significantly from baseline on all treatment periods, but a positive level of comfort was maintained in terms of gastrointestinal symptoms⁽⁶⁾.

Plasma lipids

Changes in serum lipids, lipoproteins and their ratios are shown in Fig. 1. Serum total-C and LDL-C concentrations decreased from baseline (day 0) to the end of the treatment (day 21) on the VFB diet by 8.9 (SEM 1.5) and 10.6 (SEM 3.5)%, while no changes were observed with PSY, and an increase on WB cereal by 4.2 (SEM 2.1) and 4.0 (SEM 3.0)%, respectively, was observed. At week 12, reductions in LDL-C were significantly greater with VFB compared with both PSY (-12.6 (SEM 3.5)%, $P=0.002$) and WB (-14.6 (SEM 4.2)%, $P=0.003$). The total-C:HDL-C ratio and apoB concentration were also significantly different on day 21. While a change in plasma TAG followed the same pattern, differences between the treatments were not significant.

Linear regression analysis showed viscosity to be significantly and positively associated with the decrease in LDL-C concentrations on day 21 ($P=0.001$; Pearson's correlation coefficient, $r 0.41$), whereas fibre quantity was negatively correlated with the decrease in LDL-C ($P<0.001$; $r 0.42$).

Discussion

The present study demonstrated that the addition of fibre at the recommended level to a typical NA diet is associated with a reduction in blood lipids only when a high-viscosity fibre is part of the experimental intervention with breakfast cereals. The present findings add to the evidence that the quantity of fibre in the diet is unlikely *per se* to provide information about its metabolic function, and indicate rather that there is a strong relationship between the physico-chemical properties of dietary fibre, such as viscosity, and its ability to reduce cholesterol significantly⁽⁸⁾.

These results challenge the conventional concept that fibre gravimetry is the sole factor of importance, and indicate that the level of viscosity may be an even more important factor in lowering plasma cholesterol. To the best of our knowledge, this is the first study to demonstrate the beneficial effects of increased fibre viscosity in subjects with at-target blood lipid concentrations and consuming a diet high in saturated fat and cholesterol.

While a high saturated fat intake in the diet is believed to be a contributing factor towards elevated cholesterol levels, increased consumption of dietary fibre from cereals and fruits is inversely associated with the risk of CHD. In 1994, the Food and Drug Administration authorised a health claim that low-fat diets containing soluble gel-forming fibres such as PSY and oat β -glucan lower plasma cholesterol and are thus associated with a lower risk of CHD. However, simply increasing the amount of gel-forming dietary fibre analogues in the diet results in a consistent but only modest effect on lowering lipids⁽¹⁾. According to both the Food and Drug Administration and some fibre experts, viscosity is recognised as one of the major physico-chemical properties responsible for the physiological effects of consuming soluble fibre, including reduction in blood lipids^(2,9).

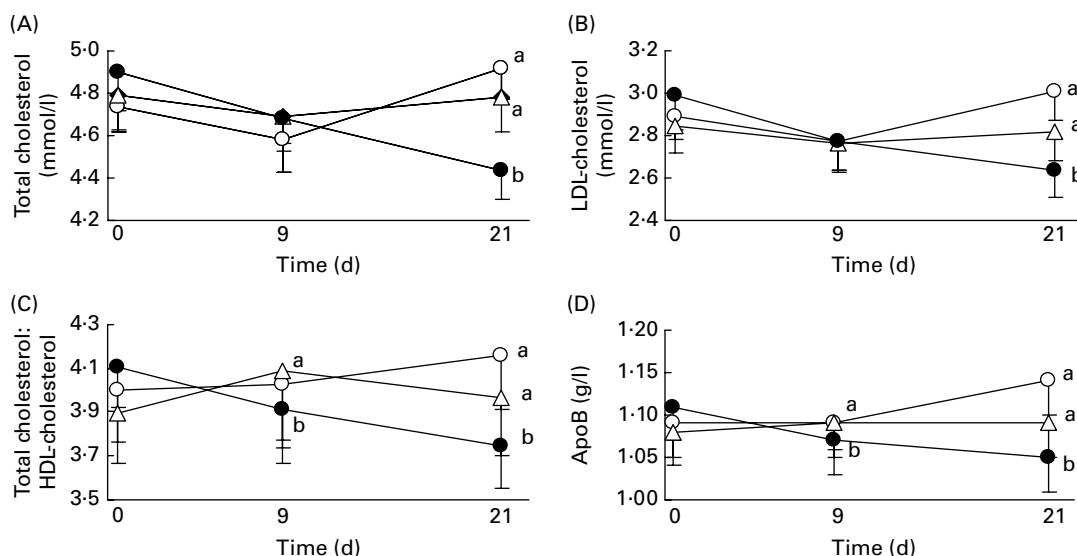


Fig. 1. Plasma lipid concentrations and lipid ratios in apparently healthy subjects ($n 23$) consuming high-fibre breakfast cereals. Wheat bran (○—○) indicates All Bran[®] (Kellogg Company, Battle Creek, MI, USA); psyllium (PSY, —△—), Bran Buds[®] with PSY (Kellogg Company); VFB (—●—), Bran Buds[®] cereal with viscous fibre blend. Values are means, with their standard errors represented by vertical bars. ^{a,b} Mean values with unlike letters were significantly different among treatments within the day ($P<0.05$). (A) Total-cholesterol; (B) LDL-cholesterol; (C) total:HDL-cholesterol; (D) apoB.

The exceptionally high viscosity of VFB occurs as a result of the nature of the complementary side chains of glucomannan and xanthan, which form a highly viscous gel matrix when combined with food in the presence of an aqueous environment within the gastrointestinal tract. It is generally accepted that the addition of a highly viscous gel-forming fibre has a marked impact on all sites of the gastrointestinal tract and affects the kinetics of nutrient bioavailability. An increase in the viscosity of intestinal contents is known to be an essential factor in affecting the rate of nutrient absorption in the small intestine, as well as the level of bacterial fermentation in the colon, both of which are instrumental processes involved in human health and disease and may contribute to reductions in blood lipid concentrations. At the end of the treatment, the total-C, LDL-C and non-HDL-C concentrations decreased by 9 and 17% on the VFB diet relative to the lower-viscosity WB and PSY treatments, and are not dissimilar compared with our previous studies^(4,5).

WB, when part of high-cereal diets, has been shown in population studies to reduce the risk of CVD; however, most interventional studies have shown that it is lipid-neutral⁽¹⁰⁾.

The partly soluble fibre PSY has been well documented to lower cholesterol in hypercholesterolaemic individuals, and addition of 7g PSY/d to a low-fat diet reduces the risk of developing CVD⁽¹⁾. In the present study, participants consumed an average of 9g PSY, yet a significant reduction in plasma cholesterol was not observed. A possible explanation for this lack of effect is that the subjects consumed a relatively high-saturated and total fat diet and had relatively low baseline cholesterol concentrations.

The design of the present study may thus limit the generalisability of the present results. Another limitation is that, unlike the other fibres, VFB was not incorporated into breakfast cereals but rather sprinkled on the cereal and was given at half the dose of the other two fibres. However, studies with PSY have demonstrated that incorporation or sprinkling is equally effective. The dose of VFB was reduced because the full dose made the cereal unpalatable, but the reduced quantity was deemed acceptable as demonstrated by the hedonic ratings of 87%. Finally, the duration of the treatment phases (21 d) was relatively short in terms of attainment of cholesterol homeostasis, and greater reductions on longer treatment may have been observed.

Conclusion

The present study demonstrated that the addition of the recommended level of fibre to a high-fat diet provides lipid-lowering benefits only when high-viscosity fibre was included in the total amount. Among apparently healthy individuals whose baseline diet composition was representative of the NA population average, the addition of high-viscosity fibre to their conventional NA diet may represent a simple preventive tool to improve the plasma lipid profile and thus reduce CVD risk outcomes.

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