Wheat bread supplemented with depolymerized guar gum reduces the plasma cholesterol concentration in hypercholesterolemic human subjects

Diane E. Blake, Caroline J. Hamblett, Peter G. Frost, Patricia A. Judd, and Peter R. Ellis

ABSTRACT Recent human studies have shown that the physiologic effects of guar gum are not diminished by partial depolymerization of its galactomannan fraction. We evaluated the effect of depolymerized guar galactomannan on fasting plasma cholesterol and triacylglycerol concentrations in healthy volunteers with moderately raised plasma cholesterol concentrations (range: 5.2–8.0 mmol/L). This study was designed as a randomized, double-blind crossover of two 3-wk feeding periods separated by a 4-wk washout period. Control and guar wheat breads were prepared by a commercial bread-making process. Subjects (n = 11) were asked to replace their normal bread with that provided, receiving control bread for one 3-wk period and guar bread for the other period, without altering their baseline diet. Subjects recorded their intake of foods for 6 consecutive days on three occasions during the study. Fasting venous blood samples (10 mL) were taken from subjects on two consecutive mornings at the start and end of each feeding period. No significant changes in body weight or dietary intake were recorded in the control and guar bread periods. There was a significant reduction (10%) in total plasma cholesterol concentration after the guar treatment (P < 0.001), mainly because of a reduction in the low-density-lipoprotein-cholesterol fraction. No changes in plasma high-density-lipoprotein-cholesterol or triacylglycerol concentrations were seen. The cholesterol-lowering effect of partially depolymerized guar gum appears to be of a magnitude similar to that of high-molecular-weight guar gum used in earlier studies. Am J Clin Nutr 1997;65:107–13.

KEY WORDS Guar gum, nonstarch polysaccharides, dietary fiber, human lipid metabolism, cholesterol, triacylglycerols

INTRODUCTION

Dietary recommendations for people with hyperlipidemia and diabetes as well as for the general population (1, 2) underline the importance of increasing the consumption of fiber-rich foods, particularly those containing water-soluble, nonstarch polysaccharides (SNSPs). However, there is little evidence that people are able to consume sufficient quantities of SNSPs, the main sources of which are limited to legumes, oats, and some fruits, to achieve the current recommended daily intake (3). Early studies in diabetic patients, for example, indicated that such diets are monotonous and patients are unlikely to adhere to such a regimen in the long term (4). This has led to interest in the use of dietary fiber supplements. The use of dietary supplements of SNSP, such as guar gum and pectin, for lowering plasma cholesterol is not a new idea because their lipid-lowering effects were shown in humans > 30 y ago (5, 6).

The biological activity of guar gum seems to depend mainly on its capacity to increase the viscosity of digesta in the upper gastrointestinal tract (7–10). Such rheological behavior is primarily dependent on the concentration, molecular weight, and particle size of the guar gum. These factors will strongly affect the hydration kinetics of the guar galactomannan and the maximum viscosity of the polymer solution (11). The rheological behavior of guar gum is also responsible for its poor palatability, particularly if it is consumed as a supplement added to drinks at concentrations known to be clinically effective. In the United Kingdom, although pharmaceutical preparations of guar gum (eg, granules) are currently available for the management of diabetes, no such products are currently available for the treatment of hyperlipidemia. The incorporation of guar gum into certain types of foods (eg, wheat bread, biscuits, breakfast cereals) is known to improve its palatability (11). Moreover, the results of some human studies have indicated that guar-containing foods are more effective in improving glycemic control than premeal drinks containing guar granules (12–14). However, it is not known whether intimate mixing of guar gum with a food or meal is important in optimizing its blood cholesterol-lowering effect. Some evidence that intimate mixing of SNSP with a food is important was provided by Wolere et al (15). These workers showed that psyllium gum, a fiber-rich seed extract of the shrub Plantago psyllium, was more effective at lipid-lowering when incorporated into a breakfast cereal than when ingested between meals.

Recent studies have indicated that depolymerized grades of guar gum, which contain galactomannan of lower molecular
weight (0.5–1.0 × 10⁶) than native guar gum (∼2.4 × 10⁶), are also clinically effective (11, 16). Furthermore, it has been known for a long time that the quality of guar bread (eg, crumb texture) can be significantly improved by using depolymerized guar gum (17). Formal sensory analysis studies showed significant improvements in the palatability of guar wheat bread when using lower-molecular-weight grades of guar gum in the bread-making recipe (11). The long-term effects of depolymerized guar gum have yet to be investigated, but some acute studies in healthy subjects (11) and non-insulin-dependent diabetic patients (16) showed that depolymerized guar gum reduces the postprandial rise in blood glucose and insulin concentrations. As an extension of this work, the present study was designed to evaluate the potential cholesterol-lowering effect of partially depolymerized guar gum in healthy human volunteers with moderately raised plasma cholesterol concentrations (5.2–8.0 mmol/L).

MATERIALS AND METHODS

Materials

A standard food grade of guar gum flour (Meyprocat 90; Meyhall Chemical AG, Rhône-Poulenc Group, Kruenzlingen, Switzerland), containing a partially depolymerized guar galactomannan, was selected for the study. Guar gum flour is a galactomannan-rich endosperm extract of the leguminous plant Cyamopsis tetragonoloba (L) Taub. The partially depolymerized galactomannan is produced by alkaline hydrolysis of the native guar gum flour. The average molecular weights of native and depolymerized samples were estimated from measurements of intrinsic viscosity (η). Fully hydrated dilute solutions of each sample were prepared, and relative viscosity (ηrel) was measured over a range of concentrations, such that 1.2 < ηrel < 2.0, on a Contraves Low Shear 30 viscometer (Rheometrics Scientific Ltd, Epsom, United Kingdom) in the Newtonian plateau region, where viscosity is independent of shear rate (11, 18). Intrinsic viscosity was obtained by combined extrapolation of (ηrel − 1)/c and ln(ηrel)/c to zero concentration (c). Molecular weight was then calculated by the Mark-Houwink relation, \( \eta = KM^\alpha \), using reported values of \( \alpha = 0.723 \) and \( K = 3.8 \times 10^{-4} \) dL/g (18), where \( M \) is the (viscosity) average molecular weight and the parameters \( K \) and \( \alpha \) are related to local stiffness of the polymer (ie, structure chain flexibility) and the long-distance structure (ie, the excluded volume, respectively). The intrinsic viscosity and calculated molecular weight for native guar gum were 15.4 dL/g and 2.38 × 10⁶, respectively, and for the depolymerized sample were 8.7 dL/g and 1.07 × 10⁶, respectively. The galactomannan content of the native and depolymerized guar gum samples was ∼84% of wet weight.

Control and guar-containing wheat breads were prepared in the form of rolls (cooked weight ∼53 and 66 g, respectively) by using the Chorleywood bread process (17), from a simple lean recipe consisting of whole-meal flour (Herdsman; Allied Mills, London), salt, fat (hydrogenated vegetable oil), fresh yeast, and variable amounts of water. Guar gum flour was incorporated into the recipe at a 10% replacement of the wheat flour. Each roll (except the control) contained 4 g guar gum (∼3.4 g galactomannan). Bread was frozen and stored at −20 °C for use throughout the trial. The wheat flour and guar gum flour were analyzed for moisture, lipid (Soxhlet; light petroleum–diethyl ether extraction), protein (Kjeldahl; nitrogen × 5.7), crude fiber (guar gum only), and ash by standard methods (19). The composition of the breads was calculated from the proximate analysis values for the wheat flour and the guar flour, and from food table values for the rest of the ingredients (20). The composition of the control and guar wheat breads is shown in Table 1.

Subjects and ethical approval

After we received ethical approval for the study from the King’s College London ethical committee, subjects were recruited from King’s College London by using a poster campaign to invite people to attend a plasma cholesterol screening. Screening was carried out by taking a finger-prick blood sample, which was then analyzed by using a Reflotron meter (Boehringer UK Ltd, Bell Lane, Lewes, United Kingdom). Fifty-seven of the 162 people screened (including 8 women) were found to have total plasma cholesterol concentrations > 5.2 mmol/L. From the latter group, one woman (aged 58 y and postmenopausal) and 19 men agreed to take part in the study. All potential subjects were asked to complete a questionnaire, which was designed to eliminate from the study anyone with a history or current complaint of gastrointestinal disturbances, on a weight-reducing regimen, receiving medication that might interfere with sterol metabolism, or not eating bread as a regular part of their diet (ie, the equivalent of 2–4 rolls/d). Volunteers found to be suitable were provided with further written and verbal details of the study, and gave their informed consent and permission for their general practitioner to be contacted to confirm that there was no medical reason why they should not participate in the study. Sixteen subjects were started on the first 3-wk feeding period and of these, 12 successfully completed the whole trial. The four subjects who did not manage to complete the study withdrew in the early stages of the trial. Two of these subjects withdrew within the first week; one stated that he had an adverse reaction after eating the guar bread (ie, nausea, headaches), and the other—the only female subject—discontinued because of personal problems that interfered with her eating habits. Two other subjects withdrew later in the study, but gave no reasons for doing so.

Table 1

<table>
<thead>
<tr>
<th>Composition of the control and guar wheat breads ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control bread</strong></td>
</tr>
<tr>
<td>% by wt</td>
</tr>
<tr>
<td>Moisture</td>
</tr>
<tr>
<td>Protein (nitrogen × 5.7)</td>
</tr>
<tr>
<td>Fat (Soxhlet)</td>
</tr>
<tr>
<td>Minerals (ash)</td>
</tr>
<tr>
<td>Available carbohydrate ²</td>
</tr>
<tr>
<td>Dietary fiber ³</td>
</tr>
<tr>
<td>Guar gum ⁴</td>
</tr>
</tbody>
</table>

¹ Mean values of duplicate samples.

² Starch, dextrins, and sugars calculated by difference: 100 − (moisture + protein + fat + ash + total nonstarch polysaccharides).

³ Dietary fiber determined as nonstarch polysaccharides derived from cell-wall material in wheat flour, guar wheat bread also contains galactomannan (5.1 % by wt of bread) derived from guar gum.

⁴ Contains ∼84% galactomannan.
Experimental protocol

Before the start of the study a 10-ml fasting venous blood sample was taken from all subjects to confirm the Reflotron measurement of plasma cholesterol and provide a full plasma lipid profile. A 3-wk run-in period was included between the initial screening and the beginning of the study to allow for any changes in diet or weight loss, which may have occurred as a result of patients being informed that their cholesterol concentration was slightly elevated. The study was designed as a randomized, double-blind crossover. Each subject received in random order the guar bread and control bread for two separate 3-wk periods, respectively, and were asked to eat ≤ 4 rolls/d. These two periods were separated by a 4-wk washout period, during which the subjects were allowed to consume their usual choice of bread. To minimize seasonal variations in dietary intake and plasma lipid concentrations of the subjects, the study was carried out during a defined time period. None of the subjects took > 10 wk to complete the active treatment and washout periods.

The subjects were asked to eat their normal diet throughout the experimental period and were advised not to alter their dietary habits or attempt to lose any weight during the study period. Each subject was asked to keep a dietary record for 6 consecutive days (using household measures), which included at least one but preferably both weekend days. A record was kept during each of the two feeding periods and once during the 4-wk washout period. Subjects were also asked to keep a detailed description (on a printed sheet) of their bowel habits and any adverse symptoms experienced during the study period. At the end of each treatment period the subjects were asked to assess the palatability of the control and guar bread rolls and also to evaluate the experimental breads in comparison with their usual choice of bread.

On two consecutive mornings at the beginning and end of each of the 3-wk bread periods, 10-ml venous blood samples were taken from subjects who had fasted overnight and abstained from alcohol. The samples were collected into plain tubes and taken directly to the laboratory for immediate analysis. Blood samples were taken on 2 consecutive days to provide information on the likely interday variation in plasma lipoproteins (21). Samples were analyzed for total plasma cholesterol, high-density-lipoprotein (HDL) and low-density-lipoprotein (LDL) cholesterol, and triacylglycerol by standard laboratory methods (see biochemical analyses).

The height of all subjects was measured without shoes at the beginning of the study by using a fixed stadiometer. Body weight of subjects not wearing shoes was also measured with a beam balance at the start and end of each of the feeding periods (on the same day the subjects gave blood samples). The height and weight measurements were used to calculate the body mass index (BMI; in kg/m²) of each subject.

Biochemical analyses

Plasma lipid concentrations were measured by standard automated methods: cholesterol by cholesterol oxidase, CHODPAP (22), with a between-batch imprecision (CV) of 2.4% at a concentration of 5.2 mmol/L and a bias of +1.5% from the UK National External Quality Assessment Scheme (NEQAS) all-method mean; triacylglycerols by glycerol kinase, glycerol phosphate oxidase (23), with Merck reagents (Merck Ltd, Poole, United Kingdom), with a between-batch imprecision of 4.3% at a concentration of 1.4 mmol/L and a bias of −3.4% from the UK NEQAS all-method mean; and HDL cholesterol (24) after precipitation of LDL cholesterol with phosphotungstate (Boehringer Mannheim UK Ltd), with a between-batch imprecision of 6.9% at a concentration of 1.14 mmol/L and mean bias of +0.8% from the Bristol (United Kingdom) HDL-cholesterol External Quality Assessment Scheme. LDL cholesterol was estimated from the Friedewald equation (25).

Dietary evaluation

Dietary records were coded and analyzed by using a computer program (FOODTABS; TAB Sanders, King’s College London, University of London) that uses food-composition data based on the 5th edition of McCance and Widdowson’s The Composition of Foods (20). The household measures of individual foods were converted into weights by using standard portion sizes (26). The values for “dietary fiber” quoted in this paper were determined by the method of Englyst et al (27), which measures dietary fiber as nonstarch polysaccharides (NSPs).

Statistical analysis

Unless otherwise stated, all results are presented as mean ± SEM of 11 subjects. Paired Student’s t tests were carried out on the start and end values of the control and guar wheat bread periods and also on the differences between the control and guar periods. Differences between the control and guar wheat bread for plasma lipid concentrations, dietary intake, and body weight changes were analyzed by repeated-measures analysis of covariance (ANCOVA) using the STATVIEW statistical package (version 4.5, Abacus Concepts Inc, Berkeley, CA). The covariables used were body weight, and energy, fat, and carbohydrate intakes. Statistical differences between the control and guar breads were accepted at P < 0.05.

RESULTS

Subject characteristics

The characteristics of the subjects at the start of the study are shown in Table 2. Although two subjects had BMIs of 30.1 and 33.1, they were not excluded from the analysis of the data, because both were muscular athletes, whose BMIs were probably more a reflection of their muscle mass than of excess fat. Data from one subject were excluded because his alcohol consumption was high enough (21.8% of energy intake) to affect his plasma lipid concentrations.

TABLE 2

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>83.7 ± 3.6 (68.1–104.4)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.76 ± 0.03 (1.64–1.92)</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>26.9 ± 0.9 (24.4–33.1)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>44.0 ± 3.6 (24–61)</td>
</tr>
<tr>
<td>Total plasma cholesterol (mmol/L)²</td>
<td>6.60 ± 0.26 (5.37–8.0)</td>
</tr>
</tbody>
</table>

¹ ± SEM; n = 11; range in parentheses.
² To convert cholesterol values from mmol/L to mg/dL, divide by 0.02586.
TABLE 3
Plasma lipid concentrations in subjects at the start and end of the control and guar wheat bread feeding periods

<table>
<thead>
<tr>
<th></th>
<th>Control bread period</th>
<th>Guar bread period</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start</td>
<td>End</td>
<td></td>
</tr>
<tr>
<td>Total cholesterol (mmol/L)</td>
<td>6.37 ± 0.21</td>
<td>6.53 ± 0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>LDL (mmol/L)</td>
<td>4.18 ± 0.15</td>
<td>4.31 ± 0.14</td>
<td>0.13</td>
</tr>
<tr>
<td>HDL (mmol/L)</td>
<td>1.26 ± 0.05</td>
<td>1.31 ± 0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Triacylglycerols (mmol/L)</td>
<td>1.84 ± 0.25</td>
<td>1.86 ± 0.32</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Start</td>
<td>End</td>
<td></td>
</tr>
<tr>
<td>Total cholesterol (mmol/L)</td>
<td>6.52 ± 0.17</td>
<td>5.89 ± 0.15</td>
<td>−0.632</td>
</tr>
<tr>
<td>LDL (mmol/L)</td>
<td>4.28 ± 0.19</td>
<td>3.81 ± 0.12</td>
<td>−0.472</td>
</tr>
<tr>
<td>HDL (mmol/L)</td>
<td>1.33 ± 0.05</td>
<td>1.23 ± 0.05</td>
<td>−0.10</td>
</tr>
<tr>
<td>Triacylglycerols (mmol/L)</td>
<td>1.96 ± 0.27</td>
<td>1.85 ± 0.25</td>
<td>−0.11</td>
</tr>
</tbody>
</table>

*1 $x \pm \text{SEM}; n = 11$. To convert cholesterol values from mmol/L to mg/dL, divide by 0.02586; to convert triacylglycerol values from mmol/L to mg/dL, divide by 0.0113.

*2 Significant difference from control and baseline values: $P < 0.001$.

Blood lipids

Mean plasma total, LDL- and HDL-cholesterol, and triacylglycerol concentrations at the start and end of the control and guar bread feeding periods are shown in Table 3. There was excellent agreement between values on consecutive days; e.g., the SD for total and LDL cholesterol, calculated from differences between paired readings for each subject, were 0.08 and 0.1, respectively. The mean plasma total cholesterol concentrations at the start of the run-in period and the start of the first treatment (control or guar) were 6.6 and 6.7 mmol/L, respectively, indicating a minimal change during the run-in phase. No significant reductions in plasma total, LDL- and HDL-cholesterol, and triacylglycerol concentrations were seen at the end of the control period relative to the baseline value. Significant reductions in plasma concentrations of total and LDL cholesterol ($F_{1,411} = 45.3, P = 0.0001; F_{1,351} = 17.0, P = 0.0002$, respectively), but not plasma HDL cholesterol and triacylglycerol ($F_{1,38} = 2.6, P = 0.11; F_{1,37} = 0.7, P = 0.41$, respectively), were seen at the end of the guar bread period relative to baseline values and the control period. A significant reduction ($P < 0.05$) in the ratio of total to HDL cholesterol was also found at the end of the guar bread period.

Body weight and diet evaluation

No significant changes in body weight were recorded in either of the treatment periods; mean body weights of subjects at the start and end of feeding periods were 83.4 ± 3.6 and 83.1 ± 3.7 kg, respectively, for the control bread phase and 84.2 ± 3.6 and 83.8 ± 3.6 kg, respectively, for the guar bread phase. Statistical analysis of the dietary data showed that there were no significant differences in nutrient intake during the different phases of the study (Table 4). The mean energy intake from dietary fat was 35-36% during the whole experimental feeding period. The range of dietary fiber (NSP) intakes of the subjects was 10-25 g/d, with a mean daily intake of 16.2 g during the control bread period and 17.2 g during the guar bread period (not including the galactomannan intake from the guar gum). The mean daily intake of control and guar wheat breads was 3.5 rolls. The guar bread provided a mean daily intake of 13.9 g guar gum (range: 8.9-16.4 g), which is equivalent to 11.7 g galactomannan. Thus, the total mean daily intake of dietary fiber during the guar bread period was 28.9 g.

Palatability and side effects

Subjects reported no difficulties with the consumption of the control or guar breads and rated the breads equally acceptable. However, most of the subjects rated the control and guar breads less palatable than their usual choice of bread. Five subjects stated that as the study progressed, both the control and guar breads became less appetizing. They attributed this to the fact that they were restricted to one type of bread and it became tedious to eat the same product every day. Four subjects commented that they would continue to eat the guar bread regularly as a replacement for their usual choice of bread if there was a greater variety of products made available. No serious side effects were reported by the subjects, although three of the subjects reported an increase in episodes of flatulence with the guar bread; two of them described the flatulence as severe, whereas the third experienced only a moderate and transient increase in flatulence.

DISCUSSION

The results of our current study in hypercholesterolemic male subjects show that fasting plasma concentrations of total and LDL cholesterol were reduced significantly at the end of the guar bread period relative to baseline and control concentrations (Table 3). No changes in the plasma HDL-cholesterol and triacylglycerol concentrations were seen. Not surprisingly, therefore, a significant reduction in the ratio of total to HDL cholesterol was found. Also, it is clear from our results that the reductions in total and LDL-cholesterol concentrations, of 10% and 11%, respectively, were caused by the inclusion of the depolymerized guar gum in the subjects’ diets, and not by changes in body weight or dietary intake. This is confirmed by ANCOVA, which showed that the covariates body weight,

TABLE 4
Dietary intake per day of subjects during the control bread, washout, and guar bread feeding periods

<table>
<thead>
<tr>
<th></th>
<th>Control bread</th>
<th>Washout</th>
<th>Guar bread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (MJ)</td>
<td>11.1 ± 0.7</td>
<td>11.0 ± 0.8</td>
<td>11.8 ± 0.8</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>111 ± 11.6</td>
<td>108 ± 10.4</td>
<td>111 ± 10.8</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>36.5 ± 2.3</td>
<td>36.0 ± 2.0</td>
<td>35.0 ± 2.3</td>
</tr>
<tr>
<td>Available carbohydrate (g)</td>
<td>314 ± 19.1</td>
<td>289 ± 19.4</td>
<td>334 ± 24.8</td>
</tr>
<tr>
<td>(% of energy)</td>
<td>45.0 ± 2.0</td>
<td>42.0 ± 1.8</td>
<td>45.3 ± 1.5</td>
</tr>
<tr>
<td>Dietary fiber (g)</td>
<td>16.2 ± 1.1</td>
<td>15.0 ± 1.2</td>
<td>17.2 ± 1.1</td>
</tr>
</tbody>
</table>

*1 $x \pm \text{SEM}; n = 11$. There were no significant differences between feeding periods, except when the intake of guar galactomannan was added to the dietary fiber value.

*2 Dietary fiber was determined by the method of Englyst et al (27), which measures nonstarch polysaccharides.

*3 Does not include 11.7 g galactomannan from guar gum; total nonstarch polysaccharide/d during guar bread period was 28.9 g.
energy, and fat did not contribute to the cholesterol-lowering effect seen at the end of the guar bread period. These covariates remained constant during the active treatment and washout periods (Table 4); for example, the mean fat intake of the subject group was found to be 35--36% of energy intake throughout the experimental phase.

The plasma lipid-lowering effect of guar gum has been investigated in a large number of clinical trials, most of which have shown reductions in total and LDL-cholesterol concentrations in healthy, diabetic, and hyperlipidemic subjects (28--31), in some studies for periods of up to 1--2 y (30, 31). A comparison of results from different clinical trials is difficult, not only because of different experimental designs and subject groups, but also because of the large variability in the physicochemical properties of the different types of guar gum used (32). Thus, it is difficult to quantify the cholesterol-lowering activity of guar gum and provide recommendations for the type and optimum dose of guar gum that should be used for therapeutic benefit. Reviews of numerous early clinical trials (33, 34) have indicated that guar gum is an effective hypocholesterolemic agent when administered at what are considered to be large doses (>15 g/d). In some individuals, such large doses can result in side effects such as flatulence, gastrointestinal discomfort, and diarrhea, although these effects appear to be transient and diminish with regular consumption of guar gum (33, 34). The results of studies in diabetic patients have indicated that at doses <15 g/d, side effects are minimal and significant reductions in plasma cholesterol can be achieved (12, 13). This is consistent with the results of the present study in which few side effects were recorded by subjects ingesting a mean daily dose of 13.9 g guar gum, except for an increase in flatulence in three of the subjects.

The hypocholesterolemic effect of depolymerized guar gum seen in the present study is consistent with the results of recent human studies showing that biological activity of guar gum is not diminished significantly after partial depolymerization (11, 16). In these studies, guar galactomannan preparations with average molecular weights of 0.5--1.0 × 10^6 were as effective as native guar galactomannan, which has a molecular weight of ≈2.4 × 10^6, in reducing the postprandial rise in blood glucose and insulin concentrations in healthy (11) and diabetic (16) individuals. The importance of molecular weight and therefore viscosity in determining the cholesterol-lowering activity of guar gum was also shown in a study of mildly hypercholesterolemic subjects (29). A high-viscosity guar gum produced a greater reduction in plasma concentrations of total and LDL cholesterol than an equivalent daily dose of medium-viscosity guar gum. No information was provided, however, about the molecular weight and galactomannan content of the guar gum used, so that differences in viscosity may be attributed to differences in the galactomannan content and/or molecular weight. A hypocholesterolemic effect was found in healthy males fed a beverage containing severely hydrolyzed guar galactomannan (molecular weight ≈20,000, as measured by HPLC) for a period of 4 wk (35). However, the intake of guar gum in this particular study was extremely high at 36 g/d, exceeding doses of guar gum used in the majority of other clinical trials.

In a more recent study with a design similar to the present one, a purified oat gum extract taken as a drink during meal-times was found to reduce plasma concentrations of total and LDL cholesterol by ≈9.2% and 10%, respectively (36). Although these reductions were achieved with daily doses of only 5.8 g oat β-glucan, the trial period was 4 wk rather than 3 wk, as in the present study. After 3 wk of feeding the oat β-glucan, a reduction in total cholesterol of ≈5.5% was measured. Note that the average molecular weight of the oat β-glucan used in this study was ≈1.2 × 10^6 (determined by using high-performance size-exclusion chromatography) (37). This molecular weight estimate is similar to the value obtained for our depolymerized sample of guar galactomannan, but is not strictly comparable because our molecular weight estimate of guar galactomannan was based on measurements of intrinsic viscosity (see Materials and Methods). Rheological measurements of purified oat β-glucan indicate that its solution properties are similar to those of guar galactomannan; thus, oat β-glucan behaves like a random-coil, nongelling polymer in aqueous solution at concentrations between 0.1% and 2% (wt:vol) (38).

The use of large doses of high-molecular-weight guar galactomannan, as reported in earlier clinical trials, inevitably leads to problems of palatability when incorporating the polymer into foods. Early recommendations about the amount of guar gum in foods were based on a compromise between sensory qualities of the food and clinical efficacy (11, 17). An important clinical benefit of using depolymerized grades of guar gum is that it is possible to incorporate much larger quantities of the galactomannan into food products without serious loss of sensory qualities. Formal sensory studies have shown that significant improvements in the quality of guar wheat bread can be achieved by using low-molecular-weight guar galactomannan (11). This result is similar to the responses of the 11 subjects in the present study who commented that both the control and guar breads were equally palatable. However, many of the subjects also commented that both types of bread were less palatable than their normal choice of bread and became less appetizing as the study progressed. This suggests that it would be useful to produce different varieties of bread and other foods containing guar gum, thus providing a wider selection of products and improving long-term compliance.

The precise mechanism by which guar gum reduces plasma cholesterol has yet to be resolved. An indirect effect of guar gum supplementation is that it may reduce the amount of fat in the diet, but this was not seen in the present study. The results obtained from animal studies suggest that the level of viscosity generated in the gastrointestinal tract is an important determinant of the hypocholesterolemic effect of guar gum and similar SNSPs (39--41). The ingestion of guar galactomannan may be responsible for enhancing bile acid and neutral sterol excretion, reducing rates of digestion and absorption of lipids and inhibiting hepatic synthesis of cholesterol. Current experimental evidence indicates that the effects of viscosity on bile acid metabolism and lipid absorption kinetics are likely to be the predominant mechanisms (39--44). In recent pig studies we showed that guar gum has the capacity to generate high levels of viscosity in the digesta at doses similar to those administered to human subjects (9, 10), even when using a lower-molecular-weight grade than that used in the present study (9). A series of in vitro experiments by Pasquier et al (45) showed that guar gum preparations of different molecular weights (0.1--1.5 × 10^6), which were estimated from measurements of intrinsic viscosity, reduced the extent of lipid emulsification and rate of lipolysis of emulsified triacylglycerols. Interestingly, one of the
guar preparations that produced a marked effect on emulsification and lipolysis was estimated to have a molecular weight of approximately $0.9 \times 10^6$, which is similar in molecular weight to that used in our current human study. The evidence to support the hypothesis that the lipid-lowering effect of guar gum is also attributed to an inhibition of hepatic cholesterol synthesis seems to be less convincing (43). If such a mechanism is involved then cholesterol synthesis may be inhibited in the liver by the presence of propionate (46), which is produced by bacterial fermentation of guar gum in the colon and subsequently absorbed into the portal blood. The results of some in vitro and in vivo studies are not consistent with this hypothesis, however (47, 48).

In conclusion, the hypocholesterolemic effect of guar gum in a group of healthy male volunteers does not appear to be diminished by a substantial reduction in molecular weight of its galactomannan component. Because bread is a staple food in many people’s diets, the development of a palatable guar-containing bread product, which can be easily incorporated into the diet with minimal alterations in normal eating patterns, is likely to increase compliance and be of considerable therapeutic use. This has significant clinical potential in the development of new food products that have value in the management of hyperlipidemia. Such products may help avoid or delay the use of cholesterol-lowering drugs, some of which have unpleasant and deleterious side effects (49).

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