

# Role of Water-Soluble Dietary Fiber in the Management of Elevated Plasma Cholesterol in Healthy Subjects

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**Guidelines for the use of water-soluble dietary fibers (WSDF) in the dietary management of elevated plasma cholesterol are not well-established. Consequently, 4 studies were conducted to explore the plasma lipid-lowering effects of a variety of WSDF. Studies were randomized, double-blind, placebo-controlled trials involving healthy men and women (plasma cholesterol >5.17 mmol/liter; >200 mg/dl). Study duration ranged from 4 to 12 weeks. The WSDF acacia gum yields a low viscosity, palatable beverage when mixed in water. However, despite its WSDF classification, acacia gum consumed for 4 weeks as the sole WSDF source (15 g of WSDF/day) or primary source in a WSDF mixture (17.2 g of WSDF/day; 56% derived from acacia gum) did not produce a significant lipid-lowering effect versus placebo. When 15 g of WSDF/day consisting of psyllium husk, pectin, and guar and locust bean gums (medium viscosity) was consumed for 4 weeks, significant reductions in cholesterol resulted (total cholesterol 8.3%, low-density lipoprotein cholesterol 12.4%;  $p < 0.001$ ) that were comparable to changes achieved with 10 g of WSDF/day from high-viscosity guar gum. The magnitude of the lipid-lowering effect was related to intake of WSDF ranging from 5 to 15 g/day (low-density lipoprotein cholesterol +0.8% [placebo], -5.6% [5 g/day], -6.8% [10 g/day], -14.9% [15 g/day];  $p < 0.01$  for trend). The effects of WSDF on plasma lipids were similar for men and women. A diet rich in selected WSDF may be a useful adjunct to the dietary management of elevated plasma cholesterol.**

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Elevated plasma total and low-density lipoprotein (LDL) cholesterol are major risk factors for coronary heart disease,<sup>1</sup> and their reduction in high-risk men leads to a lower incidence of fatal and nonfatal cardiac events.<sup>2</sup> Using the National Cholesterol Education Program (NCEP) criteria, approximately 57% of adult Americans have borderline high or high total cholesterol concentrations (>5.17 mmol/liter or >200 mg/dl) and are candidates for cholesterol lowering.<sup>3</sup> The NCEP-suggested treatment for elevated plasma cholesterol begins with dietary management.<sup>4</sup> The general aim of these dietary recommendations is to lower total and LDL cholesterol concentrations by reducing the intake of saturated fatty acids and cholesterol, and to promote weight loss in persons who are overweight by eliminating excess calories. A nutritionally adequate diet containing a diversity of foods is recommended, with emphasis placed on the increased consumption of grains, fruits and vegetables.

The addition of various water-soluble dietary fibers (WSDF) such as guar gum, psyllium husk or oat products to the typical American diet or a diet somewhat lower in fat (e.g., the American Heart Association step-one diet) tends to lower plasma cholesterol concentrations.<sup>5-7</sup> However, the role of WSDF as a component of the dietary management of elevated cholesterol is not well-established. For example, the amount of food needed in the case of oat products, and the viscosity and taste characteristics of guar gum and psyllium husk preparations serve as potential deterrents to regular consumption of these foods. In addition, very little is known about the cholesterol-lowering efficacy of other types or combinations of WSDF. The objective of the research reported here was to explore the cholesterol-lowering efficacy of different types, combinations and amounts of WSDF.

## METHODS

**Overview:** These studies were conducted to answer specific questions regarding the influence of WSDF intake on plasma lipid and lipoprotein concentrations in generally healthy men and women. Subjects were recruited using articles and advertisements in local newspapers, notices placed in large corporations and referral by private physicians. To be eligible, subjects had to be

**TABLE I** Water-Soluble Dietary Fiber Composition of Products Used in Each Study

	Study 3						
	Study 1	Study 2	WSDF Mix	Guar Gum	Study 4		
Servings/day	3	3	3	3	1	2	3
WSDF source (g/day)							
Pectin	—	—	3.9	1	1.3	2.6	3.9
Acacia gum	9.7	15	—	—	—	—	—
Psyllium husk	4.9	—	6.3	—	2.1	4.2	6.3
Guar gum	2.6	—	3.3	10	1.1	2.2	3.3
Locust bean gum	—	—	1.5	—	0.5	1	1.5
Total WSDF (g/day)	17.2	15	15	10	5	10	15
Viscosity (cp)*							
4 minutes	10.5	6.7	110	1,000	110	110	110
6 minutes	12.5	6.5	145	2,500	145	145	145
10 minutes	16.5	6.5	225	10,000	225	225	225

\*Viscosity measured at 4, 6, and 10 minutes using a Brookfield Viscosimeter (Brookfield Instrument Company, Stoughton, MA; model LVTDV).

WSDF = water-soluble dietary fiber.

aged 20 to 75 years, have plasma cholesterol concentrations  $>5.17$  mmol/liter ( $>200$  mg/dl) and plasma triglycerides  $<3.95$  mmol/liter ( $<350$  mg/dl), not be on any lipid-lowering medications or dietary fiber supplementation, have fasting glucose  $<6.6$  mmol/liter ( $<120$  mg/dl), no history of gastrointestinal diseases or evidence of such diseases on medical examination, normal liver function tests, no history or evidence of any disease that may influence lipoprotein metabolism (thyroid, cancer and so forth), and  $<130\%$  ideal body weight (1959 Metropolitan Life Insurance tables). Persons were eligible who were receiving antihypertensive medications (blood pressure stable at  $<160/95$  mm Hg), oral contraceptives or estrogen replacement therapy if they had been on a stable dose for  $\geq 6$  months and had no plans to change. All studies were approved by a committee on the use of human subjects in research, and written informed consent was obtained from each subject after the study protocol had been explained. No subject participated in  $>1$  study. The studies were initiated consecutively in the order presented.

**Treatments:** The dietary fiber mixtures, which provided predominantly WSDF, were prepared as powders in a carbohydrate base (approximately 15 g of fructose per serving) for palatability (Table I). In studies 1, 2 and 4, the placebo products were also prepared as powders with only the carbohydrate fraction present, so that equal calories (approximately 70 calories/serving) were provided to both the treatment and placebo groups. The viscosity of each WSDF mixture and placebo was measured each minute for 10 minutes after 1 serving of powder was quickly suspended in 10 oz of cold water, shaken and immediately transferred to a drinking glass. We arbitrarily defined acacia gum as low viscosity, the WSDF mixture as medium viscosity, and guar gum as high viscosity (Table I).

In study 3, a mixture of sources of WSDF (15 g of WSDF, 70 calories/serving), and a positive control (guar gum) were administered in a crossover design. Ten g of WSDF from high-viscosity guar gum (*Cyamopsis tetragonolobus*) were administered daily. The 10 g/day dose was selected for palatability and because

previous research had shown guar gum in this range to be cholesterol-lowering.<sup>7-9</sup> The guar gum was formulated in a base of artificial sweetener so that subjects in this group did not receive added calories with their fiber supplement. In each study, subjects were instructed to mix their treatment powders in an appropriate volume of water (6 to 10 oz) and to consume the beverages with their major meals. In addition, all subjects were instructed to maintain their typical eating and physical activity patterns.

**Measurements:** Measurements were obtained using similar protocols for each study. Any differences are stated in the description of the specific study. All subjects completed a screening medical history, including medications, and if their plasma total cholesterol and triglycerides were not known, a screening lipid panel was performed. Eligible subjects underwent a cardiovascular-oriented physical examination, with measurements of body height and weight, and blood pressure. Venous blood samples were obtained after a 12- to 14-hour fast on 2 separate days within a period of 8 days for analysis of plasma lipids and lipoproteins. The values obtained at these 2 visits were averaged and used as the baseline values for each subject. Two 10 ml blood samples were obtained from the antecubital vein into vacutainer tubes containing 15 mg of ethylene diamine-tetraacetic acid. Each sample was kept cool and centrifuged to obtain plasma, and the plasma was kept refrigerated until analyzed on the day after obtaining the blood sample.

High-density lipoprotein (HDL) was separated from the plasma by a precipitation procedure using dextran sulfate and magnesium chloride. Cholesterol in the remaining plasma and in the separated HDL fraction was measured by an enzymatic procedure<sup>10</sup> on a Spectrum Analyzer (Abbott Laboratories, North Chicago, IL). Triglycerides corrected for the glycerol blank were analyzed by an enzymatic ultraviolet procedure on the same Spectrum Analyzer. These analytical procedures were standardized and met the performance requirements of the Lipoprotein Standardization Program of the Centers for Disease Control (Atlanta, GA), and are

traceable to the National Reference System for Cholesterol. Very low-density lipoprotein cholesterol was estimated by dividing the triglyceride value by 5. LDL cholesterol was estimated according to the Friedewald method.<sup>11</sup>

**Randomization and follow-up:** In each study, subjects were randomized to treatment or placebo groups after all baseline data were collected. All studies were double-blinded. Follow-up evaluations were conducted at specific intervals using the same procedures as at baseline.

**Data analysis:** To determine if differences between groups at baseline or if the changes in the treatment groups compared with those in the placebo groups were significant, 2 sample *t* tests were used for studies with 2 groups (studies 1, 2 and 3), and analysis of variance for study 4, which had 4 groups. Gender differences and treatment effects were determined using 2-way analysis of variance with gender and treatment as the main factors. Significance was set at *p* < 0.05.

## RESULTS

**Study 1: EVALUATION OF A WATER-SOLUBLE DIETARY FIBER MIXTURE CONTAINING ACACIA GUM AS THE MAJOR SOURCE OF DIETARY FIBER:** Psyllium husk (*plantago psyllium*) and guar gum, consumed independently, lower plasma cholesterol concentrations.<sup>5,7-9</sup> However, their viscous nature when mixed in water can be a deterrent to palatability and can adversely affect compliance when a regimen of regular dietary intake is required. Acacia gum (*acacia senegal* or *verak*) is a WSDF source that is substantially lower in viscosity when mixed with water (Table I). This study was conducted to determine the cholesterol-lowering effectiveness of consuming approximately 17 g/day of WSDF from a mixture of dietary fiber sources, with the major WSDF source being acacia gum (56%) and the remainder from psyllium husk and guar gum.

**DESIGN:** After baseline evaluations, subjects were randomized to a double-blind, placebo-controlled trial of 12 weeks' duration. In all, 62 subjects (30 men and 32 women, mean age 57.4 ± 10.2 years, plasma cholesterol concentrations between 5.17 and 7.25 mmol/liter) met the eligibility criteria and were randomly assigned to 1 of 2 groups: a WSDF group (*n* = 32) that was prescribed 17.2 g/day of WSDF from a mixture of dietary fiber sources, or a placebo group (*n* = 30) (Table I). Adherence and side effects were monitored using a diary. Diaries were completed daily and returned every 2 weeks for review by project staff. At 6 and 12 weeks subjects completed a follow-up medical history and exam, and a fasting blood sample was obtained for measurement of plasma lipids. At baseline and 12 weeks subjects completed a Block-type food frequency questionnaire.<sup>12</sup>

**RESULTS:** Of the 62 subjects randomized to treatment or placebo, 58 completed the 12-week trial and all evaluation sessions. Dropouts included 1 patient in the placebo group (disliked taste of product) and 3 in the treatment group (diagnosis of intestinal parasite unrelated to product use [1]; gastrointestinal side effects [1]; study

**TABLE II** Study 1: Plasma Lipid Concentrations (mmol/liter: mean ± SD) and Body Weights at Baseline and in Response to a Water-Soluble Dietary Fiber Mixture of Acacia Gum, Psyllium Husk and Guar Gum (*n* = 29), and to Placebo (*n* = 29)

	Baseline	6 Weeks	12 Weeks	Percent Change*
Total cholesterol				
Placebo	6.05 ± 0.47	6.05 ± 0.65	6.02 ± 0.47	-0.5
Fiber mixture	5.97 ± 0.82	5.86 ± 0.91	5.79 ± 0.88	-3.0
LDL cholesterol				
Placebo	3.86 ± 0.57	3.74 ± 0.75	3.71 ± 0.62	-3.9
Fiber mixture	4.01 ± 0.67	3.88 ± 0.73	3.78 ± 0.73	-5.7
HDL cholesterol				
Placebo	1.54 ± 0.44	1.57 ± 0.44	1.46 ± 0.41	-5.2
Fiber mixture	1.47 ± 0.47	1.41 ± 0.31	1.39 ± 0.44	-5.4
Triglycerides				
Placebo	1.44 ± 0.64	1.57 ± 0.70	1.68 ± 0.73	+16.7
Fiber mixture	1.36 ± 0.61	1.53 ± 0.73	1.52 ± 0.70	+11.8
Body weight (kg)				
Placebo	72.5 ± 14.6	72.6 ± 15.0	73.3 ± 14.9	+1.1
Fiber mixture	71.6 ± 13.9	71.7 ± 14.1	71.9 ± 14.7	+0.4

\*Percent change for mean values from baseline to 12 weeks. No changes within or between groups from baseline to 6 or 12 weeks were statistically significant (*p* < 0.05).  
HDL = high-density lipoprotein; LDL = low-density lipoprotein.

time constraints [1]). Side effects reported were mainly transient abdominal bloating (placebo 8%; WSDF 26%) and increased stool frequency (placebo 12%; WSDF 19%) and flatus (placebo 10%; WSDF 24%), and were generally minor for both groups. Assessment of daily logs indicated 94% adherence in the treatment group, and 97% in the placebo group (number of servings taken/prescribed × 100 = % adherence).

The baseline (mean of 2 values) and treatment (at 6 and 12 weeks) values for plasma lipids and body weight are listed in Table II. At baseline, mean values for all lipid measurements were similar for the 2 groups. During the treatment period there were no significant changes in plasma lipid concentrations within or between the groups. The interaction of treatment by gender was also tested, and in no case were the changes statistically significant. Over the 12 weeks there were no significant changes in body weight or reported dietary intake of calories or major nutrients for either group.

**Study 2: THE EFFECTS OF ACACIA GUM ON PLASMA LIPOPROTEIN CONCENTRATIONS:** Acacia gum was a major WSDF source in the mixture of fibers that did not significantly influence plasma cholesterol concentrations in study 1. Acacia gum differs markedly in chemical structure and viscosity when mixed in water from that of other well-established WSDF sources, such as guar gum,<sup>12</sup> and has not been thoroughly studied for its cholesterol-lowering properties. Consequently, we evaluated acacia gum independent of other WSDF sources for its cholesterol-lowering effects.

**DESIGN:** In all, 42 subjects (21 men and 21 women, mean age 56.4 ± 9.4 years) were randomized to placebo (*n* = 22) or 15 g/day of WSDF from acacia gum (*n* = 22) for 1 month. Lipid measurements were repeated after 3 and 4 weeks of treatment. Means of the values at weeks 3 and 4 were used as the treatment values in the analysis. A 3-day diet record was completed by

**TABLE III** Study 2: Plasma Lipid Concentrations (mmol/liter; mean  $\pm$  SD) and Body Weights at Baseline and in Response to Acacia Gum and Placebo

Plasma Lipid	Placebo (n = 21)		Acacia Gum (n = 21)	
	Baseline	4 Weeks	Baseline	4 Weeks
Total cholesterol	6.83 $\pm$ 0.65	6.97 $\pm$ 0.60	6.89 $\pm$ 0.85	6.85 $\pm$ 0.91
Change		+0.14 $\pm$ 0.44		-0.04 $\pm$ 0.45
% change		+1.9%		-0.4%
LDL cholesterol	5.15 $\pm$ 0.70	5.31 $\pm$ 0.61	5.02 $\pm$ 0.84	5.04 $\pm$ 0.90
Change		+0.16 $\pm$ 0.37		+0.02 $\pm$ 0.35
% change		+3.3%		0.0%
HDL cholesterol	1.43 $\pm$ 0.40	1.35 $\pm$ 0.40	1.55 $\pm$ 0.48	1.49 $\pm$ 0.43
Change		-0.07 $\pm$ 0.12		-0.06 $\pm$ 0.17
% change		-5.4%		-3.9%
Triglyceride	1.48 $\pm$ 0.59	1.50 $\pm$ 0.59	1.49 $\pm$ 0.79	1.57 $\pm$ 0.85
Change		+0.25 $\pm$ 0.52		+0.01 $\pm$ 0.64
% change		+16.6%		+0.7%
Body weight (kg)	70.9 $\pm$ 12.7	70.9 $\pm$ 12.3	71.8 $\pm$ 12.3	72.3 $\pm$ 70.9
Change		0		0.7 $\pm$ 0.92
% change		0%		+0.9%

No changes within or between groups from baseline to 4 weeks were statistically significant (p < 0.05). Abbreviations as in Table II.

subjects during the baseline period and fourth week of treatment. Adherence and side-effects were monitored by weekly phone calls or office visits.

**RESULTS:** Of the 42 subjects randomized, 40 completed the study. One subject in each group did not complete the study owing to flu-like symptoms considered unrelated to participation in the study. The consumption of placebo or 15 g/day of WSDF from low-viscosity acacia gum produced no significant changes in plasma total, LDL and HDL cholesterol, and triglyceride concentrations and body weight during the 4 weeks of treatment, either within or between the 2 groups (Table III). In no case was the interaction of treatment by gender statistically significant for the changes in lipid concentrations. During the 4 weeks there were no significant changes in body weight or reported dietary intake.

No medically significant side effects were reported. Mild transient side effects such as bloating, increased stool frequency and flatulence were noted in 9% of the placebo group and in 36% of the acacia gum group. Adherence was >99% in both groups.

**Study 3:** WATER-SOLUBLE DIETARY FIBER MIXTURE WITH LOCUST BEAN GUM AND PECTIN SUBSTITUTED FOR ACACIA GUM: Because locust bean gum (*ceratonia siliqua*) has a chemical structure similar to guar gum,<sup>13</sup> and high-methoxyl pectin has been shown to lower plasma cholesterol concentrations,<sup>14-18</sup> these 2 WSDF sources were incorporated into a WSDF mixture in lieu of acacia gum (Table I) and evaluated in an 8-week crossover study design using guar gum as a positive control.

**DESIGN:** After baseline evaluations, 16 subjects (7 men and 9 women, mean age 52.5  $\pm$  10.8 years) were randomized to a positive control (10 g/day of WSDF from high-viscosity guar gum) or 15 g of WSDF from a mixture of 4 fiber sources (Table I). Subjects were instructed to take the guar gum immediately before their 2 major meals of the day. Lipid measurements were repeated after 3 and 4 weeks of treatment. After 4 weeks subjects were crossed over to the other treatment with measurements repeated again after 3 and 4 weeks. Means of the values at weeks 3 and 4 were used as the treatment values in the analysis. A 3-day diet record was completed by all subjects at baseline and at the end of each treatment period. Adherence and side effects were monitored by weekly phone calls or office visits.

**RESULTS:** Both WSDF products yielded significant reductions from baseline in total (p < 0.001), LDL (p < 0.001) and HDL (p < 0.01) cholesterol (Table IV). Although somewhat elevated, the changes in triglycerides were not significantly different from baseline values. There were no statistically significant differences in any of the plasma lipid changes between the 2 treatment groups, nor was there a significant interaction of treatment by gender. Body weight and reported dietary intake of calories or major nutrients did not significantly change in either group at either time period. One

**TABLE IV** Study 3: Plasma Lipid Concentrations (mmol/liter; mean  $\pm$  SD) and Body Weights at Baseline and in Response to Guar Gum and a Water-Soluble Dietary Fiber Mixture

Plasma Lipid	After Treatment (4 weeks)		
	Baseline	Guar Gum (n = 14)	Fiber Mixture (n = 14)
Total cholesterol	6.44 $\pm$ 0.55	5.82 $\pm$ 0.63	5.92 $\pm$ 0.62
Change		-0.62 $\pm$ 0.44*	-0.54 $\pm$ 0.38*
% change		-9.7%	-8.3%
LDL cholesterol	4.76 $\pm$ 0.49	4.20 $\pm$ 0.53	4.28 $\pm$ 0.61
Change		-0.55 $\pm$ 0.42*	-0.54 $\pm$ 0.38*
% change		-13.6%	-12.4%
HDL cholesterol	1.39 $\pm$ 0.24	1.30 $\pm$ 0.27	1.32 $\pm$ 0.22
Change		-0.09 $\pm$ 0.12†	-0.08 $\pm$ 0.11†
% change		-6.5%	-5.9%
Triglyceride	1.40 $\pm$ 0.45	1.54 $\pm$ 0.68	1.59 $\pm$ 0.53
Change		+0.14 $\pm$ 0.53	+0.22 $\pm$ 0.56
% change		+9.7%	+15.3%
Body weight (kg)	73.4 $\pm$ 12.7	73.6 $\pm$ 13.6	74.0 $\pm$ 13.1
Change		+0.2 $\pm$ 0.7	+0.6 $\pm$ 1.1
% change		+0.3%	+0.8%

\*Mean changes from baseline were statistically significant at p < 0.01; †mean changes from baseline were statistically significant at p < 0.05. Abbreviations as in Table II.

**TABLE V** Study 4: Plasma Lipid Concentrations (mmol/liter; mean  $\pm$  SD) at Baseline and in Response to Placebo or 5, 10 and 15 g/Day of a Water-Soluble Dietary Fiber Mixture Consisting of Pectin, Psyllium Husk, and Guar and Locust Bean Gums

Plasma Lipid	Placebo (n = 11)		Fiber Mixture (5 g/day) (n = 12)	
	Baseline	4 Weeks	Baseline	4 Weeks
Total cholesterol	6.76 $\pm$ 0.88	6.78 $\pm$ 0.88	6.59 $\pm$ 0.78	6.25 $\pm$ 0.96
Change		+0.02 $\pm$ 0.55		-0.34 $\pm$ 0.42
% change		+0.3%		-5.2%
LDL cholesterol	4.75 $\pm$ 0.77	4.79 $\pm$ 0.73	4.81 $\pm$ 0.76	4.54 $\pm$ 0.86
Change		+0.04 $\pm$ 0.47		-0.27 $\pm$ 0.37
% change		+0.8%		-5.6%
HDL cholesterol	1.72 $\pm$ 0.33	1.61 $\pm$ 0.34	1.46 $\pm$ 0.41	1.40 $\pm$ 0.44
Change		-0.11 $\pm$ 0.13		-0.06 $\pm$ 0.10
% change		-6.4%		-4.1%
Triglyceride	1.28 $\pm$ 0.80	1.59 $\pm$ 1.38	1.64 $\pm$ 0.70	1.57 $\pm$ 0.83
Change		+0.31 $\pm$ 0.68		-0.07 $\pm$ 0.47
% change		+24.2%		-4.3%
Body weight (kg)	71.8 $\pm$ 16.8	71.4 $\pm$ 16.8	69.0 $\pm$ 14.1	68.2
Change		-0.4 $\pm$ .89		-0.8 $\pm$ 2.1
% change		-0.5%		-1.2%
		Fiber Mixture (10 g/day) (n = 11)	Fiber Mixture (15 g/day) (n = 12)	
Total cholesterol	6.70 $\pm$ 0.82	6.37 $\pm$ 0.75	7.12 $\pm$ 1.17	6.25 $\pm$ 1.12
Change		-0.33 $\pm$ 0.49		-0.87 $\pm$ 0.51*
% change		-4.9%		-12.2%
LDL cholesterol	4.83 $\pm$ 0.71	4.50 $\pm$ 0.64	5.44 $\pm$ 1.09	4.63 $\pm$ 0.98*
Change		-0.33 $\pm$ 0.43		-0.81 $\pm$ 0.50
% change		-6.8%		-14.9%
HDL cholesterol	1.58 $\pm$ 0.49	1.61 $\pm$ 0.46	1.38 $\pm$ 0.33	1.25 $\pm$ 0.27
Change		-0.04 $\pm$ 0.08*		-0.13 $\pm$ 0.13
% change		-2.5%		-9.4%
Triglyceride	1.50 $\pm$ 0.75	1.32 $\pm$ 0.72	1.55 $\pm$ 0.57	1.87 $\pm$ 0.78
Change		-0.18 $\pm$ 0.49		+0.32 $\pm$ 0.28
% change		-12.0%		+20.6%
Body weight (kg)	72.7 $\pm$ 14.5	72.7 $\pm$ 14.1	73.6 $\pm$ 9.09	73.6 $\pm$ 9.04
Change		0		0
% change		0%		0%

\*Statistically significant at  $p < 0.05$  from placebo control. Abbreviations as in Table II.

subject in each group did not complete the study: 1 in the guar gum group owing to personal reasons, and 1 in the WSDF mixture group owing to nausea and headaches after 4 days in the study. Adherence to the treatment regimens was 98% in the guar gum group, and 99% in the WSDF mixture group. Side effects included abdominal bloating, and increased stool frequency and flatulence, and were mild in 72% of subjects on guar gum and in 29% on the WSDF mixture. Moderate intensity bloating or gas occurred in 2% of subjects on guar gum, but in none on the WSDF mixture.

**Study 4:** DOSE EFFECTS OF A WATER-SOLUBLE DIETARY FIBER MIXTURE: Having established in study 3 that a medium-viscosity WSDF mixture providing a total daily dose of 15 g of WSDF could significantly lower total and LDL cholesterol concentrations, a dose response study was conducted.

**DESIGN:** Forty-nine hypercholesterolemic subjects (19 men and 30 women, mean age  $56.3 \pm 9.5$  years) were randomly assigned either to placebo (n = 12) or to 5 (n = 12), 10 (n = 13) or 15 (n = 12) g/day of WSDF mixture for 1 month. Subjects were instructed to consume their WSDF with their largest meals; 1, 2 or 3

times daily depending on the dose (5, 10 or 15 g/day). Lipid measurements were repeated after 3 and 4 weeks of treatment, with the means of these 2 values used as treatment values in the analysis. A 3-day diet record was completed by subjects during the baseline period and during the fourth week of treatment. Adherence and side effects were monitored by weekly phone calls or office visits.

**RESULTS:** The changes in plasma lipids elicited by the 3 WSDF doses were compared with those in the placebo group (Table V). The decreases in total (12.2%) and LDL (14.9%) cholesterol observed for the 15 g/day group were significant compared with those in the placebo group ( $p < 0.05$ ). In addition, there was a significant trend for greater total and LDL cholesterol decreases with increasing WSDF doses from 5 to 15 g/day ( $p < 0.01$ ). HDL cholesterol concentrations decreased in all groups, with the changes in the placebo (6.4%) and 15 g/day of WSDF (9.4%) groups being greater than those in the 10 g/day group (2.5%). The plasma triglyceride response was variable, with the increase in the placebo group (24.2%) being significantly different from the decreases in the 5 (-4.3%) and 10

**TABLE VI** Effects of Various Water-Soluble Dietary Fibers on Plasma Cholesterol Concentration

Study	WSDF Source	Dose (g/day)	Duration (weeks)	Change (%)	TCb	TCf*
Jenkins <sup>19</sup>	Guar gum	15	2	-11	8.91	7.96
Bosello <sup>20</sup>	Guar gum	16	4	-12	7.83	6.86
Aro <sup>21</sup>	Guar gum	15	6	-15	8.59	7.27
Jenkins <sup>22</sup>	Guar gum	13	8	-13	-	-1.20
Penagini <sup>8</sup>	Guar gum	11	2	-16	4.81	4.03
Khan <sup>7</sup>	Guar gum	9	4	-17	4.65	3.90
Smith <sup>23</sup>	Guar gum	20	3	-14	5.46	4.68
Superko <sup>9</sup>	Guar gum	15	4	-10	6.23	5.58
Abraham <sup>24</sup>	Psyllium	21	3	-16	4.83	4.06
Bell <sup>6</sup>	Psyllium	10	8	-	4	5.90 5.65
Anderson <sup>5</sup>	Psyllium	10	8	-15	6.39	5.45
Vargo <sup>14</sup>	Pectin	15	3	-18	5.32	4.34
Kay <sup>15</sup>	Pectin	15	3	-15	5.79	4.91
Zavoral <sup>25</sup>	Locust bean gum	8-30	8	-17	8.11	6.77
Behall <sup>26</sup>	Locust bean gum	24	4	-14	5.06	4.37
Behall <sup>26</sup>	Karaya gum	24	4	-10	5.06	4.57

\*Values are group means in mmol/liter (to convert to mg/dl, multiply by 38.67). TCb = cholesterol concentration at baseline; TCf = cholesterol concentration after treatment; WSDF = water-soluble dietary fiber.

(-12.0%) g/day groups. However, no systematic pattern of significant changes related to fiber dose was observed for either HDL cholesterol or triglycerides. In no case was the interaction of treatment by gender statistically significant for any of the changes. Body weight and reported dietary intake of calories and major nutrients did not significantly change in any of the groups. Adherence in each group was >99% (total missed doses were 5 g/day = 4, 10 g/day = 1; 15 g/day = 10; placebo = 10). Three subjects did not complete the study: 1 in the 10 g/day group owing to cramps and diarrhea, 1 in the 15 g/day group owing to nausea and intestinal cramps, and 1 in the 5 g/day group owing to incomplete data collection. Other side effects reported were generally minor and transient, including abdominal bloating, and increased stool frequency or flatulence, and were reported by 36% of placebo subjects and by 18, 64 and 50% of subjects in the 5, 10 and 15 g/day groups, respectively. In 8% of the 15 g/day subjects, moderate intensity gastric side effects were reported.

## DISCUSSION

The lack of a significant effect on plasma lipoproteins seen when acacia gum was administered in beverage form, either as the major source of WSDF (study 1) or in isolation (study 2), is in contrast to the results of similarly designed studies of other types of WSDF administered in similar amounts, which have exhibited significant hypocholesterolemic effects (Table VI).

We know of only 2 published studies that examined the effect of acacia gum on plasma cholesterol. In 1 of these studies,<sup>27</sup> 5 men were administered 25 g of acacia gum in beverage form once daily for 3 weeks, which elicited a 6.3% decline in serum cholesterol concentration. In the other study,<sup>28</sup> a total of 7 men and women were administered a total of 30 g/day of acacia gum in the form of a lentil soup dish consumed twice daily, which caused a 10.4% decline in serum cholesterol con-

centration. In both of these studies, substantially larger amounts of acacia gum were administered in fewer divided doses than in the current study, which could account for its hypocholesterolemic effects. However, it should be noted that neither study included a control group, and such large amounts of added dietary fiber may lead to other changes in the diet that could lower total cholesterol. In addition, acacia gum can be obtained from many different types of acacia tree, and its cholesterol-lowering properties may vary depending on the type of tree used, the growing conditions and how the acacia gum is processed.

A number of mechanisms have been proposed to explain the cholesterol-lowering properties apparent with some WSDF sources. These effects include: (1) a binding of WSDF with bile acids or other lipids, or both, which may interfere with micelle formation in the proximal small intestine, leading to alterations in the quantity of cholesterol or fatty acids absorbed; (2) an increase in fecal excretion of bile acids that may ultimately affect hepatic synthesis of lipoproteins; and (3) fermentation of WSDF by colonic bacteria, whereupon formed gases and short-chain fatty acids may be absorbed into the portal vein and ultimately impair hepatic cholesterol synthesis.<sup>29</sup> Although the exact mechanisms remain unclear, it is possible that the physical-chemical structure of WSDF may be an important determinant of its cholesterol-lowering ability. Guar gum, a well-established hypocholesterolemic WSDF,<sup>7-9,19-23</sup> is a galactomannan derived from the guar bean. Acacia gum, a polymer of arabinose, rhamnose, galactose and glucuronic acid, is a tree exudate. Physical-chemical differences, such as viscosity, may account for differences in cholesterol-lowering properties. For example, the viscosity at 4, 6 and 10 minutes was significantly lower for the WSDF mix with acacia gum (10.5, 12.5 and 16.5 centipoises) than that for the mix with psyllium seed husk, guar and locust bean gums, and pectin (110, 145 and 225 centipoises, respectively).

When acacia gum was removed from the WSDF mixture and replaced by high-methoxyl-type pectin and locust bean gum in study 3, the combination of WSDF elicited a cholesterol-lowering effect similar to that of high-viscosity guar gum. Similar effects were seen despite a large difference in viscosity. It is possible that there is a threshold viscosity above which additional cholesterol-lowering benefits are minimal.

In examining the relation of dose of WSDF mixture to plasma lipid response (study 4), there was a significant association between fiber intake and mean plasma total and LDL cholesterol reduction, with the largest and most consistent reductions being observed with the 15 g/day dose. These findings appear to be in agreement with results of the only 2 published dose-response WSDF studies in humans that we have found, 1 of which showed that 6, 8 and 10 g of pectin administered daily for 4 weeks yielded a significant association between increasing dose and serum total cholesterol decline,<sup>30</sup> and the second showing that increasing intakes of oat bran cereal (25, 56 and 84 g/day) yielded an inverse effect on serum LDL concentrations.<sup>31</sup>

The finding that decreases in total cholesterol are largely due to reductions in LDL cholesterol (studies 3 and 4), and the lack of any systematic pattern of change in plasma HDL cholesterol and triglycerides with increasing WSDF dose (study 4) is consistent with the findings of the studies reviewed in Table VI. In the current study there were nonsignificant increases in plasma triglyceride concentrations, but these increases were just as large in the groups on placebo as in those on WSDF. It could be that the increases in triglycerides, and the decrease in HDL cholesterol were due to the 15 to 45 g/day of fructose that was used to flavor both the placebo and WSDF mixes.<sup>32</sup>

The NCEP emphasizes that diet and lifestyle modifications are the cornerstone approach to managing elevated blood cholesterol concentrations. These modifications include stopping smoking, regular exercise, losing weight if overweight, and consuming a healthy diet low in saturated fatty acids and cholesterol.<sup>4</sup> Previous studies<sup>5-7,13-24</sup> indicate that diets rich in WSDF can also substantially reduce elevated plasma total and LDL cholesterol concentrations. Unfortunately, recent estimates place the average daily intake of dietary fiber for adult Americans at approximately 7 to 14 g, depending on age, gender and race.<sup>33</sup> In addition, it appears that  $\leq 25\%$  of the total daily dietary fiber intake is obtained from WSDF-rich sources, suggesting that Americans are not fully using the potential cholesterol-lowering benefits of a diet rich in WSDF.<sup>30</sup>

An unexpected finding of the research reported here is that not all WSDF sources appear to lower cholesterol. Studies 1 and 2, which used WSDF from acacia gum as a major source and then as the only source of WSDF, demonstrated no effect on plasma cholesterol concentrations. However, studies 3 and 4 demonstrated that a mixture of WSDF sources (psyllium husk, pectin, and guar and locust bean gums) can be practically incorporated into the diet and result in significant cholesterol-lowering within 4 weeks. It appears appropriate to encourage men and women with elevated cholesterol levels to increase the WSDF in their diet as part of a comprehensive cholesterol management plan.

Additional research is needed to understand the cholesterol-lowering mechanisms and efficacy of the various types of dietary fibers. Also, long-term studies are needed to establish the potential public health benefits of lowering plasma cholesterol concentrations by the incorporation of palatable WSDF-rich foods in the diet.

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