Diets containing barley significantly reduce lipids in mildly hypercholesterolemic men and women[1–3]

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ABSTRACT

Background: Barley has high amounts of soluble fiber but is not extensively consumed in the US diet.

Objective: This study investigated whether consumption of barley would reduce cardiovascular disease risk factors comparably with that of other sources of soluble fiber.

Design: Mildly hypercholesterolemic subjects (9 postmenopausal women, 9 premenopausal women, and 7 men) consumed controlled American Heart Association Step 1 diets for 17 wk. After a 2-wk adaptation period, whole-grain foods containing 0, 3, or 6 g β-glucan/d from barley were included in the Step 1 diet menus. Diets were consumed for 5 wk each and were fed in a Latin-square design. Fasting blood samples were collected twice weekly.

Results: Total cholesterol was significantly lower when the diet contained 3 or 6 g β-glucan/d from barley than when it contained no β-glucan; the greatest change occurred in the men and postmenopausal women. HDL and triacylglycerol concentrations did not differ with the 3 amounts of dietary β-glucan. Large LDL and small VLDL fractions and mean LDL particle size significantly decreased when whole grains were incorporated into the 3 diets. Large LDL and large and intermediate HDL fractions were significantly higher, mean LDL particle size was significantly greater, and intermediate VLDL fractions were significantly lower in the postmenopausal women than in the other 2 groups. A group-by-diet interaction effect was observed on LDL fractions and small LDL particle size.

Conclusion: The addition of barley to a healthy diet may be effective in lowering total and LDL cholesterol in both men and women. *Am J Clin Nutr* 2004;80:1185–93.

KEY WORDS Barley, β-glucans, whole grains, cholesterol, triacylglycerols, lipoprotein fractions

INTRODUCTION

Cardiovascular disease (CVD) continues to be the number one cause of death in the United States despite numerous efforts to reduce its prevalence. Consumption of diets high in whole grains has been reported to have health benefits, such as a reduced risk of CVD (1, 2). These benefits have been attributed to the effects of the fiber content of whole-grain foods on risk factors, primarily on cholesterol concentration (3, 4). Other, more general, physiologic benefits of the consumption of whole grains include reduced transit time for foods, which may reduce the risk of colon cancer (5, 6), and reduced absorption of nutrients (7, 8), which may reduce glucose and insulin responses and thus the risk of obesity (9).

Epidemiologic studies often combined several fiber food sources (mixed grains and cereals, fruit, and vegetables with or without legumes), which made it difficult to determine the specific beneficial dietary component. Many of the studies in humans added either fiber supplements or fiber-containing foods to self-selected diets. Numerous studies showed that whole grains containing a high amount of soluble fiber, such as oats, are more effective in lowering blood cholesterol than are grains containing predominantly insoluble fibers, such as wheat or rice (10–13). The US Food and Drug Administration (14) allows the health claim statement that, depending on the β-glucan content, consumption of soluble fiber from oats or psyllium in a diet low in saturated fat and cholesterol may reduce the risk of CVD. Most clinical studies evaluating the effects of soluble fibers have used oats or psyllium even though barley contains at least as much β-glucan as they do (15). The purpose of this study was to examine the effects on CVD risk factors of the consumption of various amounts of β-glucan from barley, a grain not frequently consumed by Americans, in a controlled whole-grain diet in mildly hypercholesterolemic men and women. Mildly hypercholesterolemic men alone were evaluated in a previous study (16).

SUBJECTS AND METHODS

Subjects

Mildly hypercholesterolemic [total cholesterol: 5.18–6.2 mmol/L (200–240 mg/dL)], normotensive men and women who had been weight stable for 6 mo and who were not taking medication known to affect lipid metabolism or blood pressure were recruited for this study. Men were included in this study to confirm previous results because the diet was modified from the previous study. The study design was approved by the Johns Hopkins School of Public Health Institutional Review Board, and it conformed to US Government regulations governing human research. Written informed consent was obtained from each subject after an oral explanation of the study.

[1] From the Diet & Human Performance Laboratory, Beltsville Human Nutrition Research Center, Agricultural Research Service, US Department of Agriculture, Beltsville, MD.

[2] Supported by intramural agricultural research funds. Barley was provided by the National Barley Foods Council, Spokane, WA.

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TABLE 1
Prestudy characteristics of study participants[1]

		Women	
	Men ($n = 7$)	Premenopausal ($n = 9$)	Postmenopausal ($n = 9$)
Age (y)	43 ± 5[a]	47 ± 4[a]	50 ± 3[a]
Height (cm)	176.0 ± 3.7[a]	160.8 ± 2.8[b]	164.3 ± 1.3[b]
Weight (kg)	81.0 ± 4.1[a]	89.5 ± 7.8[a]	80.3 ± 7.3[a]
BMI (kg/m^2)	26 ± 1[a]	34 ± 3[b]	30 ± 3[a,b]
Percentage body fat (%)	23 ± 2[a]	38 ± 3[b]	35 ± 3[b]
Cholesterol (mmol/L)[2]	5.58 ± 0.24[a]	5.63 ± 0.22[a]	6.12 ± 0.21[a]
LDL cholesterol (mmol/L)	3.75 ± 0.21[a]	3.71 ± 0.19[a]	3.81 ± 0.19[a]
HDL cholesterol (mmol/L)	1.08 ± 0.11[a]	1.32 ± 0.10[a,b]	1.74 ± 0.10[b]
Total:HDL	5.30 ± 0.44[a]	4.47 ± 0.39[a,b]	3.53 ± 0.39[b]
Triacylglycerols (mmol/L)[3]	1.60 ± 0.42[a]	1.58 ± 0.37[a]	1.54 ± 0.37[a]

[1] All values are $\bar{x}$ ± SEM. Values in a row with different superscript letters are significantly different, $P < 0.05$.
[2] To convert units to mg/dL, multiply by 38.67.
[3] To convert units to mg/dL, multiply by 88.57.

A general clinical screening of fasting blood and urine samples was used to select subjects with mildly elevated cholesterol who had no other medical conditions and who were taking no medications that would affect lipid or glucose metabolism. Heights and weights were measured, and duplicate blood pressure readings were obtained. Subjects completed a health history questionnaire. Before subjects were accepted as participants, physicians from Johns Hopkins University School of Public Health evaluated the health history and clinical screening values for underlying disease before subjects were accepted as participants, and the physicians provided medical supervision throughout the study.

Twenty-seven subjects with mildly elevated plasma cholesterol concentrations were selected for the study. Two subjects withdrew during the study for reasons not related to the study. Prestudy characteristics of the 7 men, 9 premenopausal women, and 9 postmenopausal women who completed the study are listed in **Table 1**.

Diets and Procedures

Subjects initially were placed on an American Heart Association Step 1 diet (17) with a 7-d rotating menu for 2 wk as an adaptation period to the study regimen, dietary changes, and fiber content (**Table 2**). Initial estimates of the subjects' energy needs were made during this period. Energy intakes were adjusted proportionately in 300-kcal increments to maintain initial body weights. Breakfast and dinner were consumed Monday through Friday in the Human Study Facility. Lunch and an evening snack were packaged for off-site consumption. Weekend meals were frozen or packed in ice (or both) for home consumption. All foods were weighed to 0.5 g. Subjects were weighed daily Monday through Friday, and body weights were verified by Human Study Facility personnel. Subjects agreed to consume only the study food given to them and to consume all food items given to them. Water, selected spices, noncaloric beverages, and noncaloric sweeteners were allowed ad libitum, and the subjects recorded

TABLE 2
Nutrient content of diets[1]

	Diet			
	Step 1	Low–β-glucan	Medium–β-glucan	High–β-glucan
Energy (kcal)	2812	2788	2777	2766
Protein (g)	110	113	113	112
Fat (g)	96	96	96	96
Saturated (g)	25	27	27	27
Cholesterol (mg)	291	297	297	297
Carbohydrate (g)	388	384	385	386
Dietary fiber (g)	27	27	31	34
Soluble fiber (g)[2]	2.1	2.3	5.6	8.8

[1] Values were calculated by using NUTRITIONIST software (version 5.0; First Data Bank, San Bruno, CA). Some whole-grain foods were included in the American Heart Association Step 1 diet. At an energy level of 2800 kcal, the diets designated low–, medium–, and high–β-glucan were designed to contain approximately the same amounts of total dietary fiber but different amounts of soluble fiber added from barley: 0, 3, and 6 g β-glucan/d, respectively. Foods containing whole wheat and brown rice (low–β-glucan diet), barley (high–β-glucan diet), or a 50:50 mix (medium–β-glucan diet) included pancakes, spice cookie bars, no-bake cookies, hot cereal, granola, steamed grain, tabbouleh, and muffins.
[2] Total and soluble fiber contents were determined by Covance Laboratories Inc (Madison, WI), and β-glucan content of the barley was determined by the US Department of Agriculture (Western Region, Albany, CA).

TABLE 3
Sample menus

Breakfast	Lunch	Dinner	Evening snack
Control			
Plain pancakes	Turkey breast	Chicken breast	Ginger snaps
Pancake syrup	Swiss cheese	Gravy	
Breakfast patties	Lettuce	Egg noodles	
Margarine	Cucumber	Cole slaw	
Cranberry juice	Italian dressing	Green beans	
Low-fat (2% fat) milk	Peaches (light syrup)	Tomato juice	
(low-lactose milk)	Popcorn cakes	Chocolate cake	
	Lemonade		
Test			
Test pancakes[1]	Turkey breast	Chicken breast	Spice cookie bar[1]
Pancake syrup	Swiss cheese	Gravy	
Breakfast patties	Lettuce	Steamed rice or barley[1]	
Margarine	Cucumber	Cole slaw	
Cranberry juice	Italian dressing	Green beans	
Low-fat (2% fat) milk	Peaches (light syrup)	Tomato juice	
(low-lactose milk)	Tabbouleh[1]	Chocolate cake	
	Lemonade		

[1] Made with whole-wheat flour, whole-wheat flakes, or brown rice; barley flour, flakes, or pearls; or a 50:50 mixture of wheat and barley or rice and barley.

the consumption of these items daily. No discretionary salt was allowed.

After the 2-wk adaptation period, whole-grain foods containing soluble fiber from barley were included in the Step 1 diet. Diets were fed in a Latin-square design for 5 wk each. The 3 diets (low–, medium–, and high–β-glucan) were designed to contain approximately the same amount of total dietary fiber but different amounts of β-glucan (0, 3, and 6 g added β-glucan/2800 kcal, respectively). In the experimental menus, a test food was substituted into the Step 1 menu at breakfast, lunch, dinner, and evening snack (**Table 3**). Wheat and rice test foods (pancakes, spice cookie bar, no-bake cookies, hot cereal, granola, steamed grain, tabbouleh, and muffins) were made with whole-wheat flour, wheat flakes, and brown rice. The basic diet without the test foods and the diet containing wheat and rice test foods were designed to contain little added soluble fiber. Diets including barley flakes, barley flour, or pearled barley in the test foods (replacing the wheat or rice) contained ≥6 g β-glucan/2800 kcal as part of the total dietary fiber. Diets including test foods made with half barley and half whole wheat or brown rice contained 3 g β-glucan/2800 kcal in the total dietary fiber (Table 2). The β-glucan content of the barley used to prepare the experimental foods was determined enzymatically by the National Barley Foods Council (16) and the US Department of Agriculture (Western Region, Albany CA) with the use of American Association of Cereal Chemists method 32-23. Total and soluble fiber content of the diets were determined by using the Association of Official Analytical Chemists method 991.43, which was performed at Covance Laboratories Inc (Madison WI). Whole-wheat flour and brown rice were purchased from a local grocery store. Wheat flakes were purchased in one lot from Barry Farm Enterprises (Wapakoneta, OH). Barley flakes, barley flour, and pearled barley were produced from one lot of barley and donated by the National Barley Foods Council (Spokane, WA).

Statistical analysis

Two blood samples (separated by 1 d) were collected after an overnight fast of ≥12 h before controlled feeding began and weekly during each period. Plasma was separated and stored at −80 °C until all samples were collected. Triacylglycerol and total cholesterol concentrations were measured enzymatically with the use of an automated spectrophotometric system (Baker Instruments Corp, Allentown, PA). HDL-cholesterol concentrations were measured after other fractions were precipitated with the use of dextran sulfate and manganese chloride (18). VLDL and LDL concentrations were calculated (19). Lipid subclass fractions were measured during the last week of each period with the use of nuclear magnetic resonance spectroscopy (LipoScience, Raleigh, NC; 20). Data were statistically analyzed by analysis of variance by using a mixed-model procedure (PC/SAS, version 8.2; SAS Institute, Cary, NC). Subjects acted as their own control subjects. Data were examined for normal distribution. Triacylglycerol concentrations were log transformed for statistical evaluation. Data reported are least-squares means (±SEM). Significance was defined as $P < 0.05$. When effects were significant, mean comparisons were done with the use of Šidák-adjusted P values so that the experimentwise error was 0.05.

RESULTS

Some subjects noted some gastrointestinal discomfort during the equilibration period. The major complaints were that there was too much food and that subjects had a very full feeling after eating. Compared with the equilibration period, complaints about bloating and flatulence increased during all experimental diets; the greatest number of complaints occurred during the high–β-glucan diet.

Average body weights varied by <1 kg from the initial weight (overall average: 85.6 ± 4.5 kg) to the end of the Step 1 equilibration period (85.0 ± 4.5 kg). Subjects' average weight after

TABLE 4
Fasting lipid concentrations determined enzymatically after the equilibration and experimental dietary periods[1]

	Diet				p[2]		
	Step 1[3]	Low–β-glucan	Medium–β-glucan	High–β-glucan	Diet effect	Group effect	Diet × group interaction
Cholesterol (mmol/L)							
All subjects	5.65 ± 0.13[a]	5.44 ± 0.13[a]	5.17 ± 0.13[b]	5.12 ± 0.33[b]	<0.0001	0.090	0.437
Premenopausal women	5.39 ± 0.22	5.19 ± 0.21	5.10 ± 0.21	5.16 ± 0.22			
Postmenopausal women	6.09 ± 0.22	5.87 ± 0.22	5.54 ± 0.22	5.44 ± 0.22			
Men	5.48 ± 0.24	5.25 ± 0.25	4.88 ± 0.25	4.77 ± 0.25			
LDL cholesterol (mmol/L)							
All subjects	3.93 ± 0.13[a]	3.82 ± 0.13[a]	3.57 ± 0.13[b]	3.50 ± 0.13[b]	<0.0001	0.750	0.367
Premenopausal women	3.75 ± 0.21	3.64 ± 0.21	3.60 ± 0.21	3.56 ± 0.21			
Postmenopausal women	4.08 ± 0.21	4.02 ± 0.22	3.68 ± 0.21	3.55 ± 0.22			
Men	3.97 ± 0.24	3.79 ± 0.24	3.44 ± 0.24	3.37 ± 0.24			
HDL cholesterol (mmol/L)							
All subjects	1.34 ± 0.06[b]	1.22 ± 0.06[a]	1.22 ± 0.06[a]	1.22 ± 0.06[a]	<0.0001	<0.0004	0.169
Premenopausal women	1.23 ± 0.10	1.13 ± 0.10	1.12 ± 0.10	1.19 ± 0.10			
Postmenopausal women	1.70 ± 0.10	1.53 ± 0.10	1.54 ± 0.10	1.53 ± 0.10			
Men	1.08 ± 0.12	1.00 ± 0.12	0.99 ± 0.12	0.94 ± 0.12			
Total:HDL (mmol/L)							
All subjects	4.55 ± 0.24[a]	4.83 ± 0.24[b]	4.62 ± 0.24[a,b]	4.56 ± 0.24[a]	<0.016	<0.035	0.977
Premenopausal women	4.64 ± 0.39	4.92 ± 0.39	4.78 ± 0.39	4.66 ± 0.39			
Postmenopausal women	3.71 ± 0.39	4.00 ± 0.39	3.74 ± 0.39	3.71 ± 0.39			
Men	5.30 ± 0.44	5.60 ± 0.45	5.33 ± 0.45	5.31 ± 0.45			
Triacylglycerol (mmol/L)							
All subjects	1.92 ± 0.22	2.02 ± 0.22	1.90 ± 0.22	2.03 ± 0.23	0.858	0.568	0.784
Premenopausal women	2.06 ± 0.37	2.10 ± 0.37	1.86 ± 0.37	2.03 ± 0.38			
Postmenopausal women	1.53 ± 0.37	1.66 ± 0.38	1.63 ± 0.37	1.78 ± 0.38			
Men	2.14 ± 0.42	2.30 ± 0.43	2.22 ± 0.43	1.59 ± 0.37			

[1] All values are $\bar{x}$ ± SEM. n = 27 (all subjects), 9 (premenopausal women), 9 (postmenopausal women), and 7 (men). Values in a row with different superscript letters are significantly different, $P < 0.05$ (Šidák mean separation).

[2] ANOVA.

[3] American Heart Association Step 1 diet; low–β-glucan diet, 0 g added soluble fiber; medium–β-glucan diet, 3 g added soluble fiber/2800 kcal; high–β-glucan diet, 6 g added soluble fiber/2800 kcal. To convert cholesterol and triacylglycerol units to mg/dL, multiply by 38.67 and 88.57, respectively.

consuming all 3 whole-grain diets (low–: 84.3 ± 5.1 kg; medium–: 84.2 ± 5.1 kg; high–β-glucan: 84.2 ± 5.1 kg) was less than initial weights or weights after the Step 1 equilibration diet. The weights of the subjects did not differ significantly during the 3 experimental diets ($P = 0.73$). Energy intake during the Step 1 diet averaged 2600 kcal/d, and that during the experimental diets averaged 2725 kcal/d; this increase in intake was intended to correct the small weight loss observed during the Step 1 diet and to maintain a constant weight in subjects during the experimental diets.

Total plasma cholesterol concentrations were significantly affected by the diet consumed ($P < 0.0001$, **Table 4**) and by the length of time (in wk, $P < 0.001$; **Figure 1**) the diets were consumed. No significant interaction between diet and time was observed ($P = 0.92$). Cholesterol concentrations on average did not significantly decrease until week 4 of each period. Compared with prestudy concentrations (Table 1), overall total cholesterol was 0.5% lower after consumption of the Step 1 diet and 4%, 9%, and 10% lower, respectively, after the low–, medium–, and high–β-glucan diets. Total cholesterol concentrations after the medium– and high–β-glucan diets were significantly lower than those after the low– diet. The reductions observed by group (men, premenopausal women, or postmenopausal women) were not significantly different, and no diet-by-group interaction was observed.

Calculated LDL-cholesterol concentrations followed the same significant (Table 4, diet, $P < 0.0001$; Figure 1, wk, $P < 0.001$) pattern of reduction as that of total cholesterol. Compared with prestudy concentrations, LDL cholesterol was 3.6% lower after the Step 1 diet and significantly ($P < 0.001$) lower (8.0%, 13.8%, and 17.4%, respectively) after the low–, medium–, and high–β-glucan diets. LDL-cholesterol concentrations after the medium–and high–β-glucan diets were significantly lower than those after the Step 1 or low–β-glucan diet. No significant difference was observed among men, premenopausal women, or postmenopausal women, and no diet-by-group interaction was observed.

HDL-cholesterol concentrations were significantly affected by the diet consumed ($P < 0.001$; Table 4). Compared with prestudy concentrations, HDL-cholesterol concentrations were significantly lower ($P < 0.05$) after all 3 test diets but did not differ significantly among the 3 diets. Postmenopausal women had significantly ($P < 0.01$) higher HDL cholesterol (1.56 ± 0.10) than did men (1.00 ± 0.11) or premenopausal women (1.17 ± 0.10). Total:HDL cholesterol was significantly ($P < 0.001$) affected by the diet consumed. The ratio was highest after the low–β-glucan diet. The postmenopausal women had significantly lower total:HDL cholesterol (3.74 ± 0.38) than did the

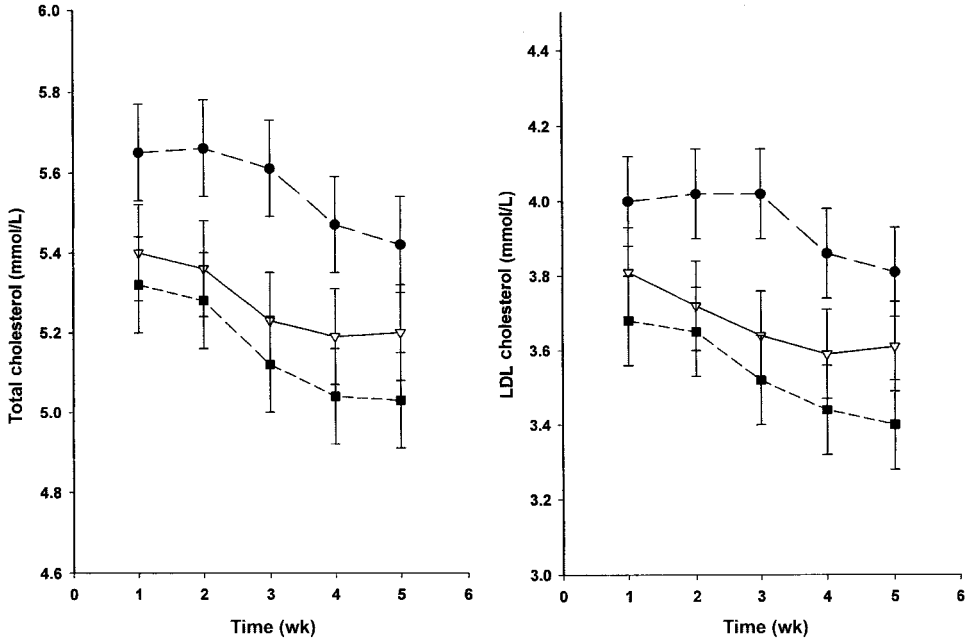

FIGURE 1. Mean weekly total and LDL cholesterol by diet: low–β-glucan diet, ●; medium–β-glucan diet, ▽; high–β-glucan diet, ■. Total and LDL cholesterol were significantly different by diet ($P < 0.0001$) and week within a diet ($P < 0.0001$), but there was no interaction between diet and week (total cholesterol: $P = 0.660$; LDL cholesterol: $P = 0.402$). Mean total and LDL-cholesterol concentrations for weeks 1 and 2 are significantly different from those for weeks 4 and 5, $P < 0.05$ (Šidák mean separation). Error bars represent SEMs.

men (5.36 ± 0.43; $P < 0.05$) or the premenopausal women (4.69 ± 0.38; $P < 0.26$). No group-by-diet interaction was observed for either the HDL-cholesterol concentrations or total: HDL cholesterol.

Overall triacylglycerol concentrations increased from the prestudy concentrations (Tables 1 and 4), but the differences were not significant. No differences were observed between the experimental diets. No significant difference was observed among men, premenopausal women, or postmenopausal women, and no diet-by-group interaction was observed. Log transformation of the triacylglycerol data did not change the results of the statistical comparisons.

Lipid fraction concentrations by diet are shown in **Table 5**. Concentrations of intermediate and large particle fractions of VLDL cholesterol; small and intermediate fractions of LDL cholesterol; and small, intermediate, and large fractions of HDL cholesterol after the Step 1 diet and the 3 experimental diets did not differ significantly. Large fractions of LDL cholesterol after the low–, medium–, and high–β-glucan diets were significantly lower than those after the Step 1 diet, and there were no significant differences between the 3 experimental diets.

Lipid fraction concentrations by group are presented in **Table 6**. The concentration of intermediate VLDL cholesterol fractions and small LDL cholesterol fractions was significantly lower and

TABLE 5
Fasting lipid fractions and particle number by diet, determined by nuclear magnetic resonance spectroscopy at the end of each controlled dietary period[1]

	Diet				
	Step 1[2]	Low–β-glucan	Medium–β-glucan	High–β-glucan	*P* for diet effect
VLDL cholesterol (mmol/L)					
Large	0.036 ± 0.016	0.059 ± 0.016	0.048 ± 0.016	0.054 ± 0.016	0.389
Intermediate	0.497 ± 0.097	0.597 ± 0.098	0.605 ± 0.097	0.558 ± 0.099	0.108
Small	0.228 ± 0.032[a]	0.184 ± 0.033[a,b]	0.174 ± 0.032[b]	0.189 ± 0.033[a,b]	<0.029
LDL cholesterol (mmol/L)					
Large	2.10 ± 0.27[a]	1.46 ± 0.28[b]	1.62 ± 0.28[b]	1.50 ± 0.28[b]	<0.002
Intermediate	1.22 ± 0.21	1.56 ± 0.22	1.56 ± 0.22	1.21 ± 0.21	0.368
Small	0.44 ± 0.23	0.54 ± 0.22	0.67 ± 0.22	0.76 ± 0.22	0.108
Particle number (nmol/L)	1530 ± 74	1539 ± 75	1501 ± 74	1497 ± 75	0.258
HDL cholesterol (mmol/L)					
Large	0.510 ± 0.061	0.520 ± 0.061	0.491 ± 0.062	0.501 ± 0.062	0.691
Intermediate	0.202 ± 0.028	0.145 ± 0.029	0.145 ± 0.028	0.170 ± 0.029	0.094
Small	0.535 ± 0.021	0.568 ± 0.022	0.551 ± 0.021	0.543 ± 0.022	0.260

[1] All values are $\bar{x}$ ± SEM. Values in a row with different superscript letters are significantly different, $P < 0.05$ (Šidák mean separation).

[2] American Heart Association Step 1 diet; low–β-glucan diet, 0 g added soluble fiber; medium–β-glucan diet, 3 g soluble fiber/2800 kcal; high–β-glucan diet, 6 g soluble fiber/2800 kcal.

TABLE 6
Fasting lipid fractions by group determined by nuclear magnetic resonance spectroscopy[1]

		Women		*P*	
	Men ($n = 7$)	Premenopausal ($n = 9$)	Postmenopausal ($n = 9$)	Group effect	Diet × group interaction
VLDL cholesterol (mmol/L)					
Large	0.060 ± 0.033	0.040 ± 0.026	0.084 ± 0.026	0.384	0.312
Intermediate	0.697 ± 0.159[a]	0.627 ± 0.116[a]	0.280 ± 0.117[b]	<0.012	0.842
Small	0.222 ± 0.052	0.221 ± 0.038	0.169 ± 0.038	0.431	0.347
LDL cholesterol (mmol/L)					
Large	1.094 ± 0.465[a]	1.746 ± 0.332[b]	2.483 ± 0.333[c]	<0.018	0.119
Intermediate	1.758 ± 0.316	1.152 ± 0.245	1.003 ± 0.247	0.172	0.969
Small	0.551 ± 0.363[a,b]	0.870 ± 0.263[a]	0.196 ± 0.265[b]	<0.023	0.659
Particle number (nmol/L)	1497 ± 126	1564 ± 89	1439 ± 90	0.356	0.333
HDL cholesterol (mmol/L)					
Large	0.350 ± 0.110[a]	0.541 ± 0.074[a,b]	0.643 ± 0.074[b]	<0.036	0.990
Intermediate	0.076 ± 0.046[a]	0.180 ± 0.034[a,b]	0.242 ± 0.034[b]	<0.014	0.538
Small	0.563 ± 0.032	0.560 ± 0.025	0.541 ± 0.025	0.763	0.565

[1] All values are $\bar{x}$ ± SEM. Values in a row with different superscript letters are significantly different, $P < 0.05$ (Šidák mean separation).

the concentrations of large LDL cholesterol fractions and large and intermediate HDL cholesterol fractions were significantly higher in the postmenopausal women than in the men or the premenopausal women. The numbers of VLDL, LDL, and HDL particles did not significantly vary with diet, group, or diet-by-group interaction.

Mean VLDL particle size (**Table 7**) showed a significant diet by group interaction. However, few a priori comparisons were significant, and no consistent pattern was evident by group or diet in the significant pairs. Mean LDL particle size was smaller after all 3 test diets than after the Step 1 diet. Mean LDL particle size was significantly larger in the postmenopausal women than in the other groups. A significant diet-by-group interaction was observed (Table 7), which appeared to be driven by the higher values after the Step 1 diet. Concentrations of LDL particle size in the men were lowest on the high–β-glucan diet; the premenopausal and postmenopausal women had no significant differences between the experimental diets.

DISCUSSION

Most research studies using food as the soluble fiber source have fed oats or oat products (1, 7, 11, 12, 21–28). Significantly lower total cholesterol (1, 21–23) and LDL-cholesterol (1, 21–23) concentrations were reported after the consumption of oat bran than after that of wheat bran or rice bran added to the self-selected diets of hypercholesterolemic subjects. Generally, no significant change was reported in triacylglycerol (1, 21, 24)

TABLE 7
Mean particle size in 7 men and 9 premenopausal and 9 postmenopausal women determined by nuclear magnetic resonance spectroscopy[1]

	Diet				*P*		
	Step 1[2]	Low–β-glucan	Medium–β-glucan	High–β-glucan	Diet effect	Group effect	Diet × group interaction
VLDL cholesterol (nm)							
Men	44.4 ± 3.9[a]	51.0 ± 4.1[b]	47.6 ± 4.1[a,b]	49.0 ± 4.1[a,b]	0.328	0.146	<0.048
Women							
Premenopausal	47.4 ± 3.3	46.4 ± 3.3	46.1 ± 3.3	47.2 ± 3.3			
Postmenopausal	53.8 ± 3.3[a,b]	59.6 ± 3.3[a]	52.4 ± 3.2[a,b]	49.8 ± 3.2[b]			
LDL cholesterol (nm)							
Men	20.7 ± 0.3[a,x]	20.6 ± 0.3[a,x]	20.6 ± 0.3[a,x]	20.2 ± 0.3[b]	<0.002	<0.005	<0.007
Women							
Premenopausal	21.1 ± 0.2[a,x,y]	20.6 ± 0.2[b,x]	20.7 ± 0.2[b,x]	20.9 ± 0.2[a,b]			
Postmenopausal	21.5 ± 0.2[a,y]	21.3 ± 0.2[b,y]	21.4 ± 0.2[a,b,y]	21.3 ± 0.2[b]			
HDL cholesterol (nm)							
Men	8.49 ± 0.13	9.61 ± 0.13	8.52 ± 0.13	8.51 ± 0.13	0.096	<0.014	0.947
Women							
Premenopausal	8.72 ± 0.09	8.67 ± 0.09	8.66 ± 0.09	8.71 ± 0.09			
Postmenopausal	8.88 ± 0.09	8.92 ± 0.10	8.86 ± 0.09	8.88 ± 0.10			

[1] All values are $\bar{x}$ ± SEM. Values in a row (a or b) or in a column (x or y) with different superscript letters are significantly different, $P < 0.05$ (Šidák mean separation).

[2] American Heart Association Step 1 diet; low–β-glucan diet, 0 g added soluble fiber; medium–β-glucan diet, 3 g soluble fiber/2800 kcal; high–β-glucan diet, 6 g soluble fiber/2800 kcal.

or HDL-cholesterol (1, 22–24) concentrations in these subjects when oatmeal or oat bran was included in the diet. The lipids of normolipemic subjects usually do not decrease with the addition of soluble fiber to their diet (1, 25, 29, 30).

Total and LDL cholesterol were significantly reduced in mildly hypercholesterolemic women after consumption of a modified Step 1 diet containing oats, but not wheat, for 6 wk (31). Mildly hypercholesterolemic men and women consuming a self-selected American Heart Association Step 2 diet averaging 8 g more soluble fiber per day than the control diet had significantly lower total cholesterol, total:HDL cholesterol, and LDL:HDL cholesterol (10). Our results with the use of a controlled Step 1 diet with 3 or 6 g β-glucan/d were similar, even though different soluble fibers were used.

Some studies reported the β-glucan (primarily from oats) content of the diets fed to the subjects (1, 3, 10, 11, 26–28, 32, 33). Similar to our results with barley, total and LDL cholesterol of hypercholesterolemic subjects decreased significantly after consumption of 3–11 g oat β-glucan/d for ≥4 wk, whereas it did not decrease after consumption of the placebo diet (3, 11, 26, 32, 33). The greatest percentage decrease in total and LDL cholesterol occurred after the higher β-glucan intake (14.5%). Uusitupa et al (33) reported that the significant reductions in LDL cholesterol observed after 4 wk were not sustained; after 8 wk, LDL-cholesterol concentrations had increased and were only 4% lower than initial concentrations. No significant decreases in total (27, 28, 34) or LDL (27, 28, 34) cholesterol after diets containing 1.9, 3.0, or 11.2 g β-glucan/d were reported. Törrönen et al (28) suggested that the lack of effect in their study could have been due to poor solubility of the β-glucan that resulted in low viscosity in the intestine. The food matrix (liquid or baked) used to incorporate the oat β-glucan into the diet also affects total: LDL and total:HDL cholesterol; both ratios were significantly lower after consumption of orange juice but not of bread and cookies containing ≈5.9 g β-glucan/d than after consumption of the control wheat fiber (35). Brown et al (36) performed a meta-analysis of 67 controlled dietary studies and calculated that, for each gram of soluble fiber from oats, psyllium, or pectin, total cholesterol and LDL-cholesterol concentrations decreased by ≈1.55 mg/dL (0.04 mmol/L). The meta-analysis showed no significant change in triacylglycerols and HDL cholesterol. The observed changes appeared to be independent of study design, treatment length, and dietary fat content.

A few studies reported barley as the source of β-glucan in the diet. Similar to our results, the addition of β-glucan from barley to the diet of mildly hypercholesterolemic men and women resulted in total and LDL-cholesterol concentrations lower than those before the study or after consumption of a control grain (15, 16, 29, 30, 37). Blood lipid concentrations of the men and women who began the study with normal cholesterol concentrations did not change (29, 30). No significant difference between oats and barley was observed, which is an indication that β-glucan and not the source was critical in lipid reduction (37). Similar to our results, the addition of the barley bran flour and barley oil (13) or whole-grain barley (16) to a Step 1 diet of hypercholesterolemic subjects resulted in a significant decrease in total and LDL cholesterol; the greatest decrease occurred after the diet containing 6 g added β-glucan/d (16). The men and the postmenopausal women reported here had lower blood lipids that resembled the pattern previously reported for men (16); premenopausal women were the most resistant to changes in blood lipids with a change in diet. Li et al (38), however, reported significant decreases in total, LDL-cholesterol, and triacylglycerol concentrations in women (average age: 20 y) after they consumed ≈3.6 g β-glucan/d extracted from barley. In contrast to other studies feeding barley, Keogh et al (39) reported no significant change in total, LDL, or HDL cholesterol or triacylglycerol concentrations after mildly hyperlipidemic men consumed 8–11.9 g β-glucan/d extracted from barley. The authors concluded that structural changes might have occurred in the β-glucan during extraction or handling.

The increased risk for coronary artery disease has been associated with a predominance of small, dense LDL particles. This is characterized by elevated triagylglycerol and lower HDL cholesterol concentrations (subclass pattern B). Sex differences were reported in lipoprotein subclass distribution patterns (40–43). Women generally have higher HDL cholesterol concentrations, larger LDL and HDL particle sizes, and lower triacylglycerol concentrations. Postmenopausal women were reported to have significantly higher total, VLDL, and LDL cholesterol and triacylglycerol concentrations; lower HDL cholesterol concentrations; smaller HDL particle size; and a strong correlation between LDL and HDL particle size (41). In contrast to the observation by Li et al (41), the postmenopausal women in the current study had the highest HDL concentrations and mean HDL particle size but no difference in triacylglycerol concentrations from those of the men. Mildly hypercholesterolemic men who consumed up to 6 g barley-derived β-glucan/d (16) and overweight men who consumed 5.5 g oats-derived β-glucan/d (44) were reported to have significantly lower LDL-cholesterol concentrations and significantly fewer LDL particle numbers than they had before the study. Although the amount of β-glucan consumed in the current study was similar to the amounts in those other studies, the change in LDL particle numbers in the current study was not significant. Davy et al (44) suggested that the decrease in small LDL-cholesterol concentrations and LDL particle numbers might contribute to the beneficial effect of oat fiber on CVD. Freedman et al (45) reported that men with relatively high concentrations of either small HDL or large VLDL particles were 3–4 times more likely to have extensive coronary artery disease than were men with concentrations below average. The postmenopausal women in our study had the highest concentrations of large LDL particles, the largest mean LDL particle size, and the smallest concentration of small LDL particles, which suggests that the men or the premenopausal women were at greater risk of CVD. However; the LDL particle size of all of our subjects remained <25 nm regardless of the diet consumed, which indicated their continued risk of coronary artery disease.

A combination of factors and mechanisms appears to contribute to the reduction in lipids observed after the consumption of barley. Mechanisms suggested for the reduction in cholesterol after increased consumption of soluble fiber include increased excretion of bile acids or neutral sterols, increased catabolism of LDL cholesterol, and reduced absorption of fat (46–48). Increased viscosity of the gastric and intestinal contents can delay gastric emptying, decrease nutrient absorption, and interfere with micelle formation. Soluble fibers were shown to be fermented in the colon (46–48) and thus to give rise to short-chain fatty acids that can be absorbed and may inhibit hepatic cholesterol synthesis. In addition to the soluble fiber, barley contains a wide range of phytochemicals, some of which are being investigated for their effect on metabolism.

Consumption of barley-containing foods and the associated soluble fiber significantly improved several CVD risk factors. These results show the potential to moderate several health risk factors through changes in food and nutrient intake without changing energy intake. The highest β-glucan intake resulted in the greatest reduction in total and LDL-cholesterol concentrations and total:HDL cholesterol, especially in postmenopausal women and men. These results indicate that dietary changes including greater consumption of whole grains including barley, higher β-glucan intake, and lower fat intake can reduce risk factors associated with CVD.

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