

Effects of Barley Consumption on CVD Risk Factors

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Heart disease continues to be the number one cause of death in the United States despite numerous strategies to reduce its prevalence. Consumption of diets high in whole grains has been reported to have beneficial health effects, such as a reduced risk of cardiovascular disease (CVD) (28). These benefits have been attributed to the effects of the fiber found in whole-grain foods on risk factors, primarily cholesterol (12). Other, more general, beneficial physiological effects of consumption of whole grains include reduced transit time for foods, which may reduce the risk of colon cancer (7), and reduced absorption of nutrients, which may reduce glucose and insulin responses and the risk of obesity (2).

Numerous studies have demonstrated that whole grains high in soluble fiber, such as oats, are more effective in lowering blood cholesterol than are grains in which fibers are predominantly insoluble, such as wheat or rice (2,12). Based on β -glucan content, the U.S. FDA (9) allows the health claim statement that 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 can contain as much or more soluble fiber (22). The purpose of this article is to evaluate the results of two studies to determine the effects of consumption of various amounts of soluble fiber from barley in a controlled whole-grain diet on risk factors for coronary heart disease in moderately hypercholesterolemic men and women.

Barley Studies

Subjects with mild to moderately elevated fasting cholesterol concentrations were selected as participants in the studies. Study 1 included 18 moderately hypocholesterolemic men. Study 2 included mildly hypocholesterolemic subjects: nine postmenopausal women, nine premenopausal women, and seven men. Prestudy characteristics of the subjects in both studies are listed in Table I.

Experimental Design. Participants in both studies followed the same regimen. Detailed descriptions of the experimental



protocol are reported in Behall and coworkers (3,4). Subjects initially were placed on the American Heart Association Step 1 diet for 2 weeks as an adaptation period to the study regimen, dietary changes, and fiber content. Water, selected spices, noncaloric beverages, and noncaloric sweeteners were allowed ad libitum, with the subjects recording the consumption of these items daily.

After the 2-week adaptation period, whole-grain foods containing soluble fiber from barley at 0, 3, or 6 g/2,800 kcal/day were included in the Step 1 diet. Diets were fed in a Latin-square design for 5 weeks each. The three diets were designed to contain approximately the same amount of total dietary fiber but different amounts of soluble fiber. Test foods (pancakes, spice cake, no-bake cookies, hot cereal,

toasted flakes, steamed pilaf, *tabbouleh*, and muffins) were made with whole-wheat flour, wheat flakes, and brown rice (low: 0 g of soluble fiber); half barley and half whole wheat or brown rice (medium: 3 g of soluble fiber); or barley flakes, barley flour, and pearly barley (high: 6 g of soluble fiber). The nutrient content of the diets and sample menus have been reported previously (3,4).

Two fasting blood samples (separated by 1 day) were collected before controlled feeding began and weekly during each period after an overnight fast of at least 12 hr. Triacylglycerol and total cholesterol (HDL, VLDL, and LDL) concentrations were determined. Data were analyzed statistically by analysis of variance using a mixed model procedure (PCSAS, version 8.2, SAS Institute, Cary, NC). Each subject served as their own control. Data were examined for normal distribution. Triacylglycerol concentrations were log-transformed for statistical evaluation. Differences of least squares means were determined for significant factors. Data reported are least squares means plus/minus standard error of the mean. Statistical significance was defined as $P < 0.05$. When effects were significant, mean comparisons were done with Šidák-adjusted P values.

Findings. Total plasma cholesterol concentration was significantly affected by the diet consumed ($P < 0.0001$; Figs. 1 and 2) and by the length of time (by week; $P < 0.001$) the diet was consumed. Compared with prestudy concentrations (Table I), total cholesterol concentrations after consumption of low, medium, and high soluble fiber diets were 14, 17, and 20%, respectively, lower for moderately hypocholesterolemic men in Study 1 and 4, 9, and 10%, respectively, lower for all subjects in Study 2. For the mildly hypercholesterolemic population in Study 2, men had the greatest decrease (14.5%) after consuming the high soluble fiber diet, followed by postmenopausal (10.7%) and premenopausal (8.4%) women. Calculated LDL cholesterol concentrations (Figs. 1 and 3) followed the pattern of reduction observed for total cholesterol. Compared with prestudy concentrations, LDL cholesterol concentrations were significantly lower after subjects consumed low, medium, and high soluble fiber diets.

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Compared with prestudy concentrations, HDL cholesterol was significantly lower after the Step 1 diet in Study 1 (Fig. 1), but not in Study 2 (Fig. 4). HDL cholesterol concentrations after consumption of low, medium, and high soluble fiber diets were not significantly different in either study. In both studies the ratio of total cholesterol to HDL cholesterol was highest after consumption of the low soluble fiber diet ($P < 0.001$). Postmenopausal women had the highest HDL cholesterol concentrations, and men had the lowest concentrations. Compared with pre-study concentrations, triacylglycerol concentrations (Figs. 1 and 5) after consumption of the Step 1 and three soluble fiber diets were not significantly different. No gender difference was observed.

The number and size of VLDL, LDL and HDL particles did not significantly vary with diet. LDL particle size did show significant variation between diets, but no difference was observed due to the amount of soluble fiber in the diet. The mean number of LDL particles significantly decreased after consumption of all experimental diets. The mean number of LDL particles was lowest (12%) after consumption of the high soluble fiber diet for men in Study 1. Premenopausal and postmenopausal women in Study 2 showed no significant differences among experimental diets. In study 2, LDL particles were significantly larger for postmenopausal women than for men or premenopausal women. LDL mean size and number of particles remained in the high-risk range after consumption of all diets in both studies.

Soluble Fibers and Cholesterol

Most research studies with food as the source of soluble fiber have used oats or oat products (1,2,6,7,12,14,27,28). When added to the self-selected diets of hypercholesterolemic subjects, oat bran, compared with wheat bran and rice bran, has been shown to significantly lower total (10,19, 20,28) and LDL (1,6,14,28) cholesterol concentrations. Brown and coworkers (6) performed a meta-analysis of 67 controlled dietary studies and calculated that for each gram of soluble fiber from oats, psyllium, or pectin, total and LDL cholesterol decreased by approximately 1.55 mg/dL (0.04 mmol/L). The observed changes appear to be independent of study design, treatment length, and dietary fat content. Generally, no significant change was reported in triacylglycerol (6,4,15,28) or HDL cholesterol (1,6, 15,28) concentration in these subjects when oatmeal or oat bran was included in the diet. Similar reductions in lipids were observed by Newman and coworkers (24) after subjects consumed oats or barley, an indication that β -glucan content and not the source is critical in lipid reduction. For hypercholesterolemic subjects, the addition of barley bran flour and barley oil (19) to a Step 1 diet resulted in a significant decrease in total and LDL cholesterol. For normolipemic subjects, the addition of soluble fibers to the

diet usually did not result in a decrease in lipids (11,23,24,26,28).

A few studies have reported on the β -glucan (primarily from oat sources) content of diets fed to subjects (5,27,28). Similar to the results from Studies 1 and 2, total and LDL cholesterol levels in hypercholesterolemic

subjects decreased significantly after consumption of 2–11 g of oat β -glucan per day for 4–5 weeks compared with a placebo diet (5). Studies have reported no statistically significant decreases in total or LDL (18,27) cholesterol levels after consumption of diets containing 1.9, 3.0, or 11.2 g of β -

Table I. Prestudy characteristics (mean \pm SEM) of men and women participating in two barley studies

Characteristic	Men (Study 1)	Men (Study 2)	Premenopausal Women (Study 2)	Postmenopausal Women (Study 2)
Number of subjects	18	7	9	9
Age (years)	45.6 \pm 3	43 \pm 5	47 \pm 4	50 \pm 3
Height (cm)	179.3 \pm 1.5	176.0 \pm 3.7	160.8 \pm 2.8	164.3 \pm 1.3
Weight (kg)	91.7 \pm 4.8	81.0 \pm 4.1	89.5 \pm 7.8	80.3 \pm 7.3
BMI (kg/m ²)	28 \pm 1	26 \pm 1	34 \pm 3	30 \pm 3
Body Fat (%)	NA	23 \pm 2	38 \pm 3	35 \pm 3
Cholesterol (mmol/L)	6.08 \pm 0.20	5.58 \pm 0.24	5.63 \pm 0.22	6.12 \pm 0.21
LDL cholesterol (mmol/L)	3.99 \pm 0.20	3.75 \pm 0.21	3.71 \pm 0.19	3.81 \pm 0.19
HDL cholesterol (mmol/L)	1.10 \pm 0.04	1.08 \pm 0.11	1.32 \pm 0.10	1.74 \pm 0.10
Total/HDL cholesterol ratio	5.7 \pm 0.3	5.30 \pm 0.44	4.47 \pm 0.39	3.53 \pm 0.39
Triacylglycerols (mmol/L)	2.13 \pm 0.20	1.60 \pm 0.42	1.58 \pm 0.37	1.54 \pm 0.37

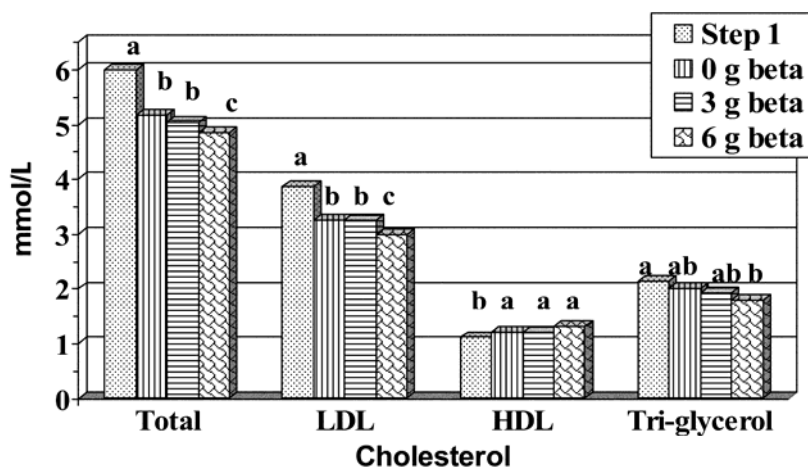


Fig. 1. Total, LDL, and HDL cholesterol and triacylglycerol concentrations for men after consumption of diets containing varying amounts of barley β -glucan. Significant differences were observed in total ($P < 0.0001$), LDL ($P < 0.001$), and HDL ($P < 0.003$) cholesterol and triacylglycerol ($P < 0.053$) concentrations after consumption of four controlled diets.

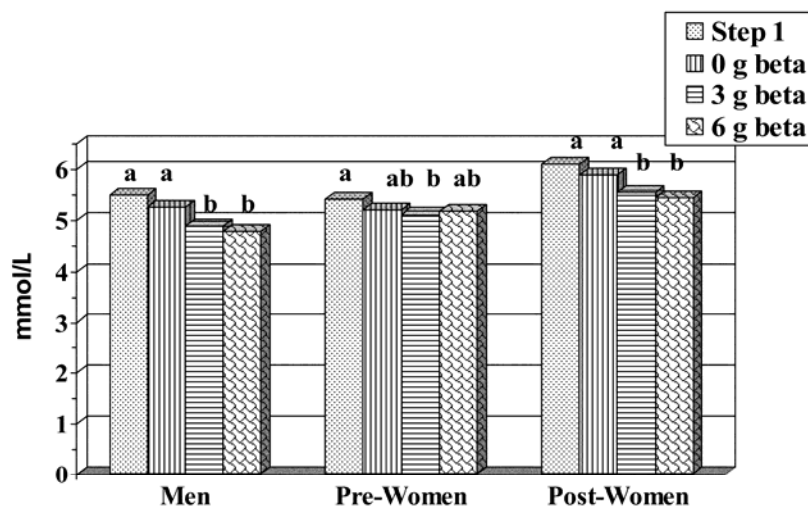


Fig. 2. Total cholesterol concentrations for men and pre- and postmenopausal women after consumption of diets containing varying amounts of barley β -glucan. Significant differences were observed in total cholesterol ($P < 0.0001$) concentrations after consumption of four controlled diets, with no significant difference between groups ($P < 0.09$).

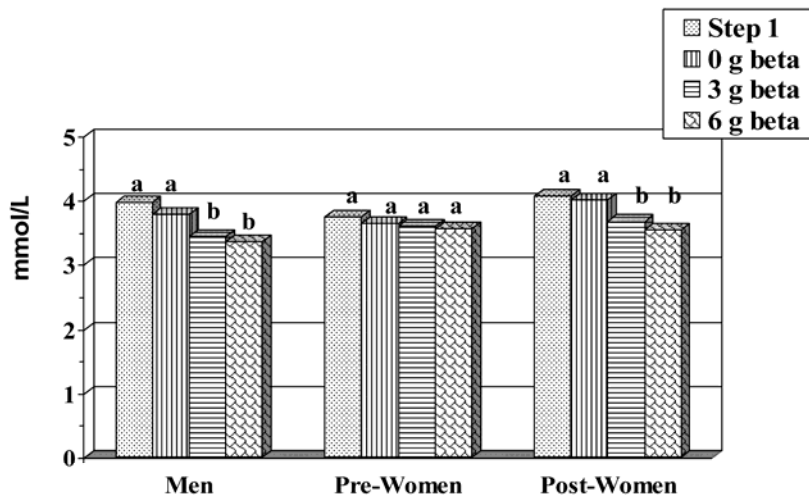


Fig. 3. LDL cholesterol concentrations for men and women after consumption of diets containing varying amounts of barley β -glucan. Significant differences were observed in LDL cholesterol ($P < 0.0001$) concentrations after consumption of four controlled diets for men and postmenopausal women, with no significant difference between groups ($P < 0.75$).

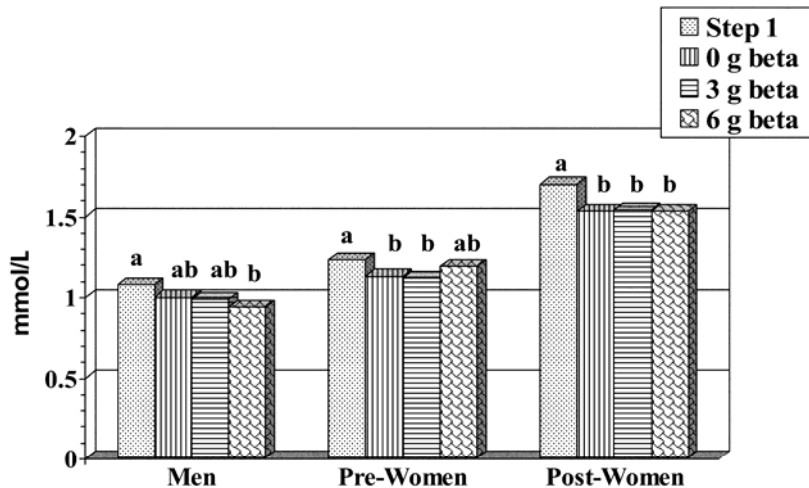


Fig. 4. HDL cholesterol concentrations for men and women after consumption of diets containing varying amounts of barley β -glucan. Significant differences were observed in HDL cholesterol ($P < 0.0001$) concentrations after consumption of four controlled diets. The concentrations for postmenopausal women were significantly higher than those for men and premenopausal women ($P < 0.001$).

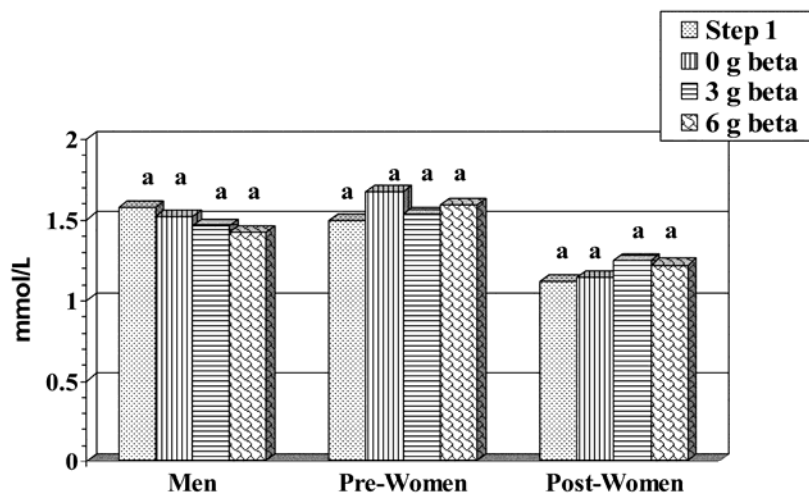


Fig. 5. Triacylglycerol concentrations for men and women after consumption of diets containing varying amounts of barley β -glucan. No significant differences were observed in triacylglycerol ($P < 0.86$) concentrations after consumption of four controlled diets or between groups ($P < 0.57$).

glucan per day. Törrönen and coworkers (27) suggest that the lack of effect in their study could have been due to the poor solubility of the β -glucan, resulting in low viscosity in the intestine.

The addition of soluble fiber from barley to the diet of moderately hypercholesterolemic men and women resulted in lower total and LDL cholesterol concentrations compared with prestudy concentrations or concentrations after a control diet (11,16, 22–24). Premenopausal women in Study 2 were the most resistant to changes in blood lipids with a change in diet. However, Li and coworkers (16) reported significant decreases in total and LDL cholesterol concentrations and reduced triacylglycerol concentrations in 10 young women (averaging 20 years of age) after they consumed approximately 3.6 g of β -glucan from barley per day. In contrast to most studies utilizing barley as the source of β -glucan, Keogh and coworkers (13) reported no significant change in total, LDL, or HDL cholesterol or triacylglycerol concentrations after mildly hyperlipidemic men consumed 8–11.9 g of β -glucan extracted from barley per day. The authors concluded that structural changes may have occurred in the β -glucan during the extraction process or product handling.

Increased risk for coronary heart disease has been associated with a predominance of small, dense LDL particles. This is characterized by elevated triacylglycerol and lower HDL cholesterol concentrations (subclass pattern B). Gender differences have been reported in lipids and lipoprotein subclass distribution patterns (17,25). Women generally have lower triacylglycerol and higher HDL cholesterol concentrations and larger LDL and HDL particles. Postmenopausal women have been reported to have significantly higher total, VLDL, and LDL cholesterol and triacylglycerol concentrations and lower concentrations of HDL cholesterol, with smaller HDL particles and a strong correlation between LDL and HDL particle size (17). In contrast, women participating in Study 2 had significantly higher HDL concentrations and larger LDL and HDL particles than the men; triacylglycerol concentrations were not significantly different. In contrast to observations made by Li and coworkers (17), postmenopausal women participating in Study 2 had the highest HDL concentrations and largest mean HDL particle size, with no difference in triacylglycerol concentrations from those of the men.

Overweight men who consumed an oat (5.5 g of β -glucan per day) or wheat supplement had a significant reduction in LDL cholesterol concentration, number of LDL particles, and ratio of LDL to HDL cholesterol from prestudy concentrations after consuming oats, whereas lipids increased after consuming wheat (8). The authors suggest that the decrease in small, dense LDL cholesterol concentration and number of LDL particles without changes in triacylglycerol or HDL cholesterol concentrations may con-

tribute to the beneficial effect of oat fiber on CVD. Freedman and coworkers (10) 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 men with concentrations below average. A similar pattern was observed in the reduction in number of LDL particles and large LDL cholesterol particle concentration after consumption of the three whole-grain diets in Studies 1 and 2, but the changes did not significantly reduce the risk for coronary heart disease.

Conclusions

A combination of factors and mechanisms appears to contribute to the reduction of lipids observed after consumption of barley. Suggested mechanisms for lowered cholesterol after increased soluble fiber consumption include increased excretion of bile acids or neutral sterols, increased catabolism of LDL cholesterol, and reduced fat absorption (20,21). Increased viscosity of the gastric and intestinal contents can delay gastric emptying, decrease nutrient absorption, and interfere with micelle formation. Studies have shown that soluble fibers ferment in the colon (20,21), giving rise to short-chain fatty acids that can be absorbed and may inhibit hepatic cholesterol synthesis. In addition to 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 its associated soluble fiber β -glucan, significantly improved several cardiovascular risk factors. These results indicate that dietary changes, including addition of barley, increased total whole-grain consumption, higher fiber intake, and lower fat intake, can reduce risk factors associated with CVD.

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