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## Intake of whole grains, refined grains, and cereal fiber measured with 7-d diet records and associations with risk factors for chronic disease<sup>2</sup>

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### Abstract

**Background**—Research studies examining foods are important, because they account for biological interactions that might otherwise be lost in the analysis of individual nutrients. Single-nutrient studies are also needed to explore the mechanisms by which foods may be protective.

**Objective**—Our objective was to examine associations between whole grains, refined grains, and cereal fiber and chronic disease risk factors.

**Design**—In a cross-sectional analysis of participants in the Baltimore Longitudinal Study of Aging, associations between dietary intakes and risk factors were examined with multivariate linear regression analysis. Dietary intakes were assessed with 7-d dietary records and quantified in g/d.

**Results**—Compared with subjects in the lowest quintile (Q1) of whole-grain intake, subjects in the highest quintile (Q5) had lower body mass index (BMI; in kg/m<sup>2</sup>; Q1: 25.5; Q5: 24.8; *P* for trend <0.0001) and weight (Q1: 75.0 kg; Q5: 72.4 kg; *P* for trend = 0.004) and smaller waist circumference (Q1: 87.4 cm; Q5: 85.0 cm; *P* for trend = 0.002). Whole grains were also inversely associated with total cholesterol (*P* for trend = 0.02), LDL cholesterol (*P* for trend = 0.04), and 2-h glucose (*P* for trend = 0.0006). Associations between cereal fiber and anthropometrics and plasma lipids were similar. In subgroup analyses, refined grains were positively associated with fasting insulin among women (*P* for trend = 0.002).

**Conclusions**—Similar associations of whole grains and cereal fiber with weight, BMI, waist circumference, plasma cholesterol, and 2-h glucose were observed, suggesting that cereal fiber and its constituents may in part mediate these relations. Refined grains were associated with fasting insulin among women but not men. Additional research should explore potential interaction effects with BMI, sex, age, and genes.

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The author's responsibilities were as follows—PKN: was responsible for the design and analysis for this report and drafted the manuscript; JM and PB: created the database for this study; DM and LF: contributed to data collection for the Baltimore Longitudinal Study of Aging; KLT: contributed to the database development and oversaw the HNRCA collaboration with the BLSA. All authors made critical comments during the preparation of the manuscript and fully accept responsibility for the work.

## Keywords

Whole grains; refined grains; fiber; diet records; risk factors

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## Introduction

Carbohydrate nutrition, including food sources, chemical structures, and physiologic properties, is an important area of research. The role of nondigestible polysaccharides (ie, fiber) in a healthy diet has been appreciated for many decades (1), leading to statements by both the American Dietetic Association (2) and the Council on Scientific Affairs (3) that fiber consumption is related to decreased risk of several diseases, including colon cancer, heart disease, diabetes, diverticulosis, and obesity. More recently, significant associations were observed between whole-grain intakes and cardiovascular disease and stroke (4), cancer (5, 6), diabetes (7,8), obesity (9), and the metabolic syndrome (10,11). Refined grains are the counterpart to whole grains, but evidence is conflicting about associations with metabolic and anthropometric variables (10–13), although some evidence shows that consumption of refined grains is associated with a risk of cancer (14,15).

Whole grains contain many bioactive components that might be responsible for their protective effect, including fiber, resistant starch, and oligosaccharides, as well as vitamins, minerals, phytate, phytoestrogens, and phytosterols (16). Research studies examining food groups such as whole grains are important, because they account for biological interactions that might otherwise be lost in an analysis of individual nutrients. However, studies examining single nutrients such as cereal fiber are also needed to increase our understanding of the mechanisms by which whole grains may be protective. Additional research is also needed to further examine whether intake of refined grains is associated with risk factors for chronic disease.

The objective of this study was to examine associations of the intakes of whole grains, refined grains, and cereal fiber measured with 7-d dietary records and quantified in gram weights with selected risk factors for chronic disease among adults participating in the Baltimore Longitudinal Study on Aging (BLSA). An additional goal was to explore whether associations with risk factors were modified by sex or body mass index (BMI; in kg/m<sup>2</sup>).

## Subjects and Methods

### Study population

The BLSA is an open prospective cohort study that began in 1958 with the goals of studying the physical, mental, and emotional effects of aging among healthy, active persons; the original study design and data collection have been described in detail elsewhere (17). Briefly, initial study participants were white male community-dwelling volunteers 27–88 y of age living in Baltimore, Maryland. The study protocol was expanded in 1978 to include women and minorities. Participants return approximately every 12–24 mo for repeated measurements (eg, height, weight, body composition analysis). Subjects were also invited to participate in the (optional) dietary assessment portion of the study, in which 7-d diet records were used to assess dietary intakes. The Institutional Review Boards of the Johns Hopkins Bayview Medical Research Center and the Gerontology Center approved the BLSA protocol, and all subjects gave written informed consent for their participation.

Initially, 1572 persons completed at least one 7-d diet record during the course of the study. Of those, we excluded subjects who had not completed  $\geq 4$  d of the record, as well as those with implausible energy intakes or statistical outliers for total energy intake ( $<2510$  or  $>16\,736$  kJ/d for women;  $<3347$  and  $>17\,572$  kJ/d for men) or who were missing information on age ( $n =$

53). Our baseline population therefore included 1516 participants. Because of the limited number of persons with both repeated dietary data and outcome measures, this analysis only included participants from the first visit at which participants had complete dietary and outcome data. Thus, for each outcome, our sample size varied somewhat, as follows: BMI and weight ( $n = 1502$ ), waist circumference ( $n = 1404$ ), total cholesterol ( $n = 1444$ ), HDL cholesterol ( $n = 1029$ ), LDL cholesterol ( $n = 1025$ ), triacylglycerols ( $n = 1430$ ), diastolic and systolic blood pressures ( $n = 1464$ ), fasting glucose ( $n = 1324$ ), 2-h glucose ( $n = 882$ ), fasting insulin ( $n = 460$ ), and 2-h insulin ( $n = 455$ ).

### Dietary assessment

Dietary intake was assessed by 7-d dietary records, and subjects were instructed by trained dietitians how to assess portion size, weigh foods, and complete the records. Reports that detail the dietary collection methods and dietary intake in the BLSA population were published previously (18,19). Food records were completed at home by the participant and sent back to the study center. Before 1993, subjects were given food models and a booklet of food pictures to help them assess portion size. Since 1993, subjects were given a portable scale to weigh food portions. Participants were contacted by telephone with any questions about their records.

Dietary records were originally coded and entered into a nutrient database maintained by the BLSA, whereas diet records completed since 1993 were coded and entered into the Minnesota Nutrient Database at Tufts University. Dietary data collected before 1993 were then reentered in the Minnesota Nutrient Database, and nutrient intakes were back adjusted to correct for changes in the food supply (eg, nutrient content because of fortification of cereals) with data from the US Department of Agriculture to correspond to appropriate time intervals (20,21).

### Measurements of whole grains, refined grains, and cereal fiber

For this study, we used all available dietary data from the BLSA to create a whole-grains database. In brief, all foods containing grains or mixed dishes with foods containing grains, either whole or refined, were identified and then assigned the best-matched pyramid code from the Pyramid Servings Database, a reference database of servings per 100 g from 30 food groups, including 3 grain groups (total grain, whole grain, and nonwhole grain). We then used the Continuing Survey of Food Intakes by Individuals 1994–1996 recipe database to disaggregate mixed dishes that contained grains (either whole or refined) to obtain gram weights of individual ingredients. Some foods could not be disaggregated to the ingredient level, in which case the reference gram amount of grains was determined by multiplying by the pyramid definition of a serving (eg, a grain serving of one slice of bread contains 16 g of flour and a grain serving of one serving of cereal contains 28 g of flour). Once the reference database was completed, we calculated the absolute amount of grains consumed by multiplying the gram amount eaten by the reference values/100 for each day of the dietary record, and values for all days were summed and divided by the total number of days of dietary records to obtain an average intake.

Cereal fiber was measured by summing the fiber content from cereal foods, which includes the starchy grains produced from grass plants. Thus, our quantification of cereal fiber included fiber from whole grains (eg, wheat, rice, corn, oats, etc) and all foods made from grains, including ready-to-eat and hot cereals, bread, pasta, crackers, sweet baked goods, and salty snacks. Whole grains, refined grains, and cereal fiber were adjusted for total energy intake with the nutrient residual method.

### Outcome assessment

Our outcome variables included various risk factors for chronic disease. Anthropometric and clinical measurements were obtained by following standardized procedures (22) that have been

fully described elsewhere (23). In summary, weight and height were measured for each subject at each visit, from which BMI was calculated. Waist circumference was measured with the use of an inelastic tape at the narrowest part of the torso at the end of expiration (23), roughly equivalent to the bottom of the ribcage for most persons. Blood pressure was measured from a sitting position with the use of a standard protocol (24).

For lipid measurements, an antecubital venous blood sample was drawn from study subjects after an overnight fast. As previously described (25,26), concentrations of triacylglycerols and total cholesterol were measured by enzymatic method (Abbott Laboratories ABA-200 ATC Biochromatic Analyzer; Irving, TX). HDL cholesterol was measured by the dextran sulfate–magnesium precipitation procedure (27), and LDL cholesterol was estimated by the Friedewald formula (28).

As described previously, fasting plasma glucose and 2-h glucose concentrations were obtained with the use of an oral glucose tolerance test after overnight fasting, in which the glucose dose was 40 g/m<sup>2</sup> body surface area, corresponding to an average dose of 78 g in men and 68 g in women (29). Plasma glucose was measured by the glucose oxidase method (Beckman Instruments, Fullerton, CA). Plasma insulin was measured in duplicate by radioimmunoassay (30).

### Covariate assessment

Race-ethnicity, physical activity, smoking, education, and vitamin supplement use were determined by questionnaire at the time dietary records were collected. Physical activity was measured by an adapted version of the Harvard Alumni questionnaire, which asked participants about all daily activities (eg, activities at home, work, and during recreation or sports). The amount of time spent for each activity was summed across all activities to determine the daily energy output per body weight (in kJ/kg) and was described previously (18,32).

### Statistical analysis

We first examined the relations between the intakes of whole grains, refined grains, and cereal fiber and the sample characteristics at the time of the first visit, as well as associations with nutrient intakes. We also explored associations between the 3 dietary variables with the use of Spearman correlation coefficients. Our main analyses used multivariate linear regression to estimate separately the relation between whole grains, refined grains, and cereal fiber with each of our outcome variables. As such, we built separate regression models for each dietary variable, and each was divided into quintiles of intake. For example, we fit models estimating the relation between whole grains (in quintiles) and each risk factor (BMI, weight, waist circumference, total cholesterol, HDL cholesterol, LDL cholesterol, diastolic blood pressure, systolic blood pressure, fasting glucose, 2-h glucose, fasting insulin, and 2-h insulin). Similar models were fit for refined grains and cereal fiber. We used a generalized linear model to estimate the least-squares means for each outcome, and each model was adjusted for age, sex, race, education, decade of visit, vitamin supplement use, total energy, percentage of energy from saturated fat, and alcohol. The whole-grain models were further adjusted for intakes of refined grains, and the refined-grain models were further adjusted for intakes of whole grains.

Models that predicted lipid outcomes were further adjusted for BMI, use of lipid-lowering medication, and diagnosis of hypercholesterolemia. Models that predicted blood pressure were further adjusted for BMI, use of blood pressure–lowering medication, and diagnosis of hypertension. Models that predicted glucose and insulin outcomes were further adjusted for BMI, use of oral hypoglycemic medication, and diagnosis of diabetes. We also repeated the analyses for the above outcomes excluding subjects rather than adjusting for these variables in the analysis (ie, subjects with a diagnosis of diabetes were excluded from the glucose and

insulin analyses) to remove the possibility of residual confounding. We created interaction terms to test whether the effects of the intakes of whole grains, refined grains, and cereal fiber on risk factors were modified by sex in all models and whether the effects were modified by BMI in our models that estimated fasting glucose, 2-h glucose, fasting insulin, and 2-h insulin.

We performed a number of additional analyses to test the robustness of our models. First, we tested models for each relation with further adjustment for physical activity on a limited subset of subjects for whom such data were available. In addition, we tested all associations limiting our dataset to subjects entering the study in 1980 or later to reduce the potential of a cohort effect. We also added a quadratic term for age to our models to determine whether it improved model fit. All analyses were performed with the use of SAS for WINDOWS, version 9.1 (SAS Institute, Cary, NC).

## Results

Age was positively related to the intakes of whole grains and cereal fiber ( $P$  for trend  $< 0.0001$ ) and inversely related to the intake of refined grains ( $P$  for trend = 0.004) (Table 1). BMI was inversely related to whole-grain intake ( $P$  for trend = 0.001), and subjects in the highest quintile of whole-grain intake had the lowest prevalence of overweight (39% compared with 54% in the lowest quintile;  $P = 0.0003$ ); similar associations were seen for cereal fiber intake. The highest percentages of women were found in the highest quintile of whole-grain intake (40% compared with 15% in the lowest quintile;  $P < 0.0001$ ) and cereal fiber intake (38% compared with 21% in the lowest quintile;  $P < 0.0001$ ) and in the lowest quintile of refined-grain intake (56% compared with 18% in the highest quintile;  $P < 0.0001$ ).

Intake of whole grains was positively related to intakes of total energy, percentage of energy from carbohydrates, total fiber, folate, magnesium, vitamin E, and vitamin B-6 ( $P < 0.0001$  for all) and inversely related to percentage of energy from total and saturated fats, alcohol, and cholesterol ( $P < 0.0001$  for all); similar associations were observed with cereal fiber ( $P < 0.0001$  for all), with the exception of vitamin B-6 ( $P = 0.20$ ) (Table 2). Intake of refined grains was positively related to total energy intake and to percentage of energy from carbohydrates ( $P < 0.0001$  for both) and inversely related to percentage of energy from protein, total fat, saturated fat, fiber, alcohol, and magnesium ( $P < 0.05$  for all). In addition, whole grains were positively correlated with cereal fiber ( $r = 0.77$ ,  $P < 0.0001$ ) and negatively correlated with refined grains ( $r = -0.18$ ,  $P < 0.0001$ ) (data not shown).

Whole grains were significantly related to each of the anthropometric outcomes in multivariate adjusted models (Table 3). Compared with subjects in the lowest quintile (Q1) of intake, subjects in the highest quintile (Q5) had lower BMI (Q1: 25.5 kg/m<sup>2</sup>; Q5: 24.8 kg/m<sup>2</sup>;  $P$  for trend  $< 0.0001$ ) and weight (Q1: 75.0 kg; Q5: 72.6 kg;  $P$  for trend = 0.004) and smaller waist circumference (Q1: 87.4 cm, Q5: 85.0 cm;  $P$  for trend = 0.002). Whole grains were also inversely associated with total cholesterol and LDL cholesterol ( $P$  for trend = 0.02 and  $P$  for trend = 0.04), as well as with 2-h glucose ( $P$  for trend = 0.0006). Associations with blood pressure, insulin, and fasting glucose variables were not significant. No interaction was observed between sex and whole grains in any of our models, nor was an interaction observed between BMI and whole grains in our models for fasting glucose, 2-h glucose, fasting insulin, or 2-h insulin ( $P > 0.05$  for all interaction terms). Associations remained similar when further adjusted for physical activity.

A significant interaction was observed between intake of refined grains and sex in relation to fasting insulin ( $P = 0.04$ ). When a stratified analysis was performed with the use of quartiles of refined-grain intake (rather than quintiles, to preserve statistical power), a positive association was observed among women (quartile 1: 57.0; quartile 5: 81.1;  $P$  for trend = 0.002)

(Figure 1), and the association remained significant and of similar magnitude when further adjusted for cereal fiber and physical activity, and when women with a diagnosis of diabetes were excluded from the analysis (data not shown). No association was seen among men (quartile 1: 73.9; quartile 4; 76.0;  $P$  for trend = 0.48). A significant interaction with sex was also detected in the analysis of refined grains and 2-h insulin ( $P = 0.03$ ). However, associations among women (quartile 1: 289 mmol/L; quartile 5: 367 mmol/L;  $P$  for trend = 0.11) and men (quartile 1: 439 mmol/L; quartile 5: 528 mmol/L;  $P$  for trend = 0.29) were not significant in stratified analyses. No significant relations between refined grains and any of the other risk factors (BMI, weight, waist circumference, total cholesterol, HDL cholesterol, LDL cholesterol, triacylglycerols, systolic blood pressure, diastolic blood pressure, fasting glucose, 2-h glucose, fasting insulin, and 2-h insulin) were observed ( $P > 0.05$  for all; data not shown).

Similar to the findings with whole grains, cereal fiber was inversely associated with BMI ( $P$  for trend  $< 0.0001$ ), weight, ( $P$  for trend = 0.0004), waist circumference ( $P$  for trend  $< 0.0001$ ), and total cholesterol ( $P$  for trend = 0.005) (Table 4), and the associations remained significant when further adjusted for physical activity (data not shown). Cereal fiber was also inversely associated with 2-h glucose (Q1: 8.05 mmol/L; Q5: 6.48 mmol/L;  $P$  for trend = 0.02) in the multivariate-adjusted model but was no longer significant when further adjusted for physical activity ( $P$  for trend = 0.09). No interaction with sex or BMI was observed in any of the models. A quadratic term for age improved model fit ( $P < 0.001$ ) and was retained in all models.

## Discussion

One of the main objectives of this study was to examine independent associations between whole grains and cereal fiber with risk factors for chronic disease. We found that whole grains were significantly inversely associated with anthropometric variables (weight, BMI, and waist circumference), plasma lipid measures (total cholesterol and LDL cholesterol), and 2-h glucose. Cereal fiber was also related to these variables, and the magnitude of effects was similar. The aleurone layer and cell walls of whole grains, largely composed of nonstarch polysaccharides (32), also include many additional bioactive components such as phytochemicals (eg, phytic and phenolic acids), phytoestrogens (eg, lignans and isoflavones), antioxidants, vitamins, and minerals (eg, potassium, magnesium, and selenium) (33). Indeed, many of these bioactive constituents are insoluble and bound to cell wall materials (34), and they act independently and synergistically to confer many protective health effects (16,35–38). Our findings suggest that cereal fiber, its bioactive components, or both may mediate the associations with whole grains examined in this study.

Several other studies have shown similar inverse associations with anthropometric variables for whole grains (11,12,39) and cereal fiber (40,41). Fiber contributes to satiation, satiety, and the secretion of gut hormones (9), thereby affecting body weight and body composition through its effect on energy intake. McKeown et al (10) also observed comparable associations for whole grains (odds ratio: 0.67; 95% CI: 0.48, 0.91) and cereal fiber (odds ratio: 0.62; 95% CI: 0.45, 0.86) with risk of metabolic syndrome. Unlike other studies (11,39,41), our study showed significant inverse associations between whole grains and cereal fibers with total cholesterol, and whole grains were also inversely associated with LDL cholesterol. Jensen et al (42) also reported a significant inverse association between whole grains and total cholesterol ( $P = 0.02$ ). The relation between dietary fiber and cholesterol is thought to be mainly due to soluble fibers rather than insoluble fibers (43,44), but phytosterols (16) and phytoestrogens (35) may also affect cholesterol metabolism. No significant associations were observed between whole grains and blood pressure in our study, as seen in 2 other cross-sectional studies (11,39), but a small intervention study observed a decline in blood pressure after a whole-grain diet (45). Cereal fiber intake was also unrelated to blood pressure in our study. Although 2 meta-analyses reported a small but significant inverse association between total fiber and blood pressure

(46,47), neither specifically addressed the role of cereal fiber, so whether cereal fiber specifically is associated with blood pressure requires more research.

Antioxidants and minerals present in whole grains and cereal fiber may contribute to insulin sensitivity (9,48), and fiber may also be related to insulin sensitivity through effects on delayed gastric emptying. We observed a significant inverse association between whole grains and cereal fiber and 2-h glucose, and the magnitude of the effects was quite similar for both variables. McKeown et al (39) observed null associations between whole grains and 2-h glucose and 2-h insulin in a cross-sectional study of persons in the Framingham Offspring Study, and whole grains were also unrelated to fasting insulin in 2 large cohort studies (42). Although Lairon et al (41) saw no significant association between whole grains and fasting glucose, Sahyoun et al (11) showed an inverse dose-response relation ( $P$  for trend = 0.01). A small crossover study among overweight persons reported improved insulin sensitivity after an intervention with cereal fiber (49), and several other studies have shown significant associations between whole grains and plasma glucose (39) and insulin sensitivity (50,51) among subjects with higher BMI, suggesting effect modification. Inconsistent findings on associations of whole grains or cereal fiber in relation to insulin or glucose measures may be due to differences in study design and dietary assessment methods, inadequate testing of interaction effects, or chance.

We observed a significant positive association between refined grains and fasting insulin among women but not men. Interaction effects are more likely to occur by chance and often are not reproducible (52), so our findings need to be interpreted with caution. However, our result is supported by recent results from the Hypertension Genetic Epidemiology Network study, which found a quantitative trait locus influencing fasting insulin in female, but not male, subjects (53). Refined grains are major contributors to glycemic load, and several reviews support a positive association between glycemic load and insulin resistance or glycemic control (54–56). That the percentage of energy from total carbohydrate in the highest quintile of refined grains (50.5%) and whole grains (51.7%) is so similar underscores the importance of differentiating between whole and refined foods when making dietary choices. Indeed, a small randomized crossover feeding study among overweight subjects with hyperinsulinemia observed 10% lower fasting insulin when consumption with refined grains were replaced with whole grains (57), as seen in a trial that included a reduction in refined grains as part of a comprehensive dietary intervention (58,59). Note also that we observed a significant interaction between refined grains and sex in relation to 2-h insulin. Although the observed effects were in the expected direction, we likely had inadequate power to achieve statistical significance in stratified analyses.

Refined grains were not significantly associated with any other risk factor in this study. As mentioned, findings about refined grains and risk factors for chronic disease are inconsistent. Decreasing intake of refined grains was associated with a smaller weight change in one study (12), whereas increasing intake of refined-grain breakfast cereals was inversely related to weight gain and BMI in another (13). Refined grains were positively associated with fasting glucose among older adults (11) and hypertriglyceridemic waist phenotype (60). Refined grains were also positively associated with risk of metabolic syndrome in 2 cross-sectional studies (10,11), but neither showed associations with individual risk factors. Those results and ours suggest that the effect of refined grains on measures of insulin and glucose may be modified by age (11), BMI (4,33), and sex, probably due to differences in glucose tolerance and insulin sensitivity.

There are several limitations to our study. First, our study is cross-sectional; thus, our results do not allow us to make inferences about the directions of our associations and may be obfuscated by reverse causation. Although a longitudinal study would be stronger, our data are

limited by the small numbers of subjects who have repeated measures of both dietary and risk factor data. An additional limitation is that our study sample, which is selected from an open cohort study, includes subjects across several decades. However, a cohort effect was not observed in an earlier study in this population (19). In addition, our models were adjusted for decade of the visit, and results remained similar when we limited our study to data from 1980 or later. Our study has a small sample size for some of our outcome variables; thus, we probably had insufficient power to detect and explore potential interactions. Finally, our study did not include markers of genetic variability, which are increasingly understood to modify the effect of diet on disease risk factors such as plasma lipids (61).

In conclusion, our study shows significant and similar associations of whole grains and cereal fiber with weight, BMI, waist circumference, and total cholesterol. Refined grains were positively associated with fasting insulin among women but not men. Longitudinal studies are needed to reproduce these findings, and special attention should be dedicated to exploring potential interactions with BMI, sex, age, and genes.

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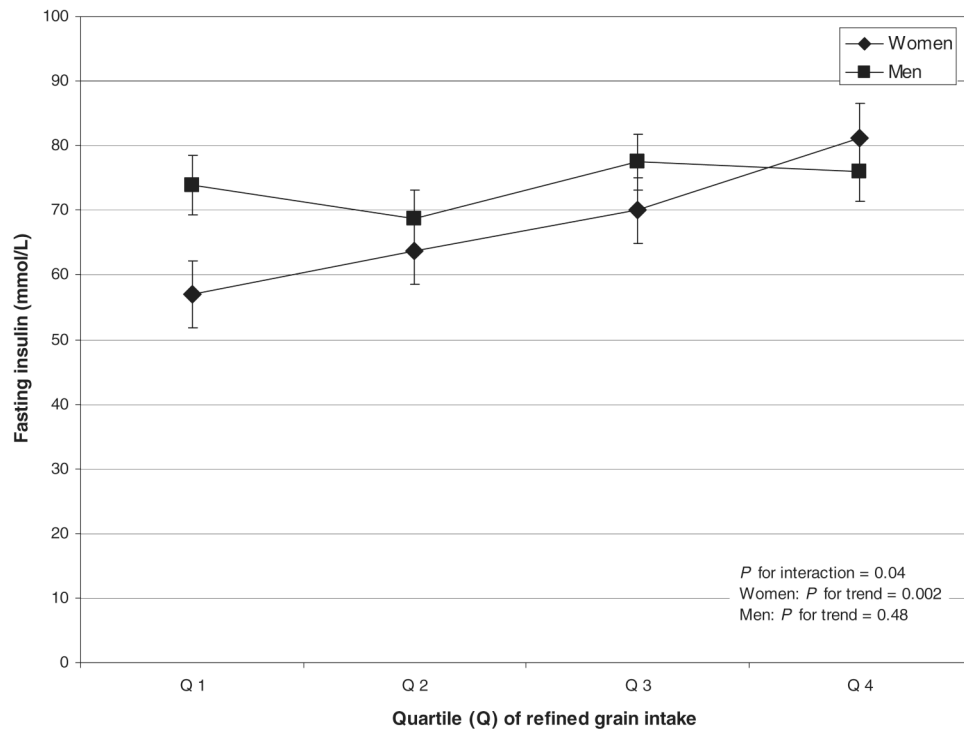
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**Figure 1.**

Association between quartiles of intake of refined grains (in g/d) and fasting insulin (in mmol/L) among 183 women and 277 men participating in the Baltimore Longitudinal Study of Aging. Because of differences in intakes, intake quartiles (Q1–Q4) were derived separately for women and men, as follows: women (Q1: 32.5; Q2: 46.7; Q3: 56.1; Q4: 73.7) and men (Q1: 49.4; Q2: 64.8; Q3: 80.8; Q4: 102.0). Values are  $\bar{x} \pm \text{SEM}$ , estimated with the least-squares means from a linear regression analysis (generalized linear model). Models are adjusted for age, age<sup>2</sup>, total energy, decade of visit, race, education, vitamin supplement use, BMI, smoking, percentage of energy from saturated fat, alcohol, whole-grain intake, and diabetes diagnosis.

**Table 1**  
Sample characteristics of 1516 men and women participating in the Baltimore Longitudinal Study on Aging at the time of the first visit at which participants had complete dietary data<sup>1</sup>

Sample characteristic	Whole grains <sup>2</sup>			Refined grains <sup>3</sup>			Cereal fiber <sup>4</sup>		
	Q1	Q5	P <sup>5</sup>	Q1	Q5	P <sup>5</sup>	Q1	Q5	P <sup>5</sup>
Age (y) <sup>6</sup>	52.4 ± 1.0 <sup>7</sup>	63.3 ± 0.9	<0.0001	59.4 ± 1.0	55.4 ± 1.0	0.004	53.3 ± 1.0	63.8 ± 0.9	<0.0001
BMI (kg/m <sup>2</sup> ) <sup>8</sup>	25.5 ± 0.2	24.5 ± 0.2	0.001	24.9 ± 0.2	25.2 ± 0.2	0.51	25.7 ± 0.2	24.3 ± 0.2	<0.0001
Weight (kg) <sup>8</sup>	74.9 ± 0.6	72.9 ± 0.7	0.01	73.5 ± 0.7	73.9 ± 0.7	0.78	75.5 ± 0.7	72.2 ± 0.7	0.001
Waist circumference (cm) <sup>8</sup>	86.0 ± 0.7	83.5 ± 0.6	0.0006	84.1 ± 0.6	85.6 ± 0.7	0.10	86.1 ± 0.6	82.9 ± 0.6	<0.0001
Physical activity (kcal/kg) <sup>8</sup>	13.8 ± 0.3	14.3 ± 0.4	0.13	13.3 ± 0.3	15.0 ± 0.3	0.0005	13.4 ± 0.3	14.7 ± 0.3	0.007
BMI ≥ 25 (%)	54	39	0.0003	45	48	0.89	55	38	0.0003
Hypertension (%)	10	10	0.35	7	7	0.62	9	7	0.06
Female (%)	15	40	<0.0001	56	18	<0.0001	21	38	<0.0001
White (%)	89	86	0.26	90	87	0.22	87	88	0.06
Vitamin users (%)	14	38	<0.0001	32	31	0.30	22	37	0.001
Current smokers (%)	26	4	<0.0001	10	12	0.23	22	4	<0.0001
College graduate (%)	65	71	0.37	67	70	0.03	68	71	0.004

<sup>1</sup> Sample sizes differed because of missing data, as follows: BMI and weight ( $n = 1500$ ), waist circumference ( $n = 1106$ ), vitamin use ( $n = 1185$ ), education ( $n = 1500$ ), and physical activity ( $n = 1028$ ). Nutrients are adjusted for total energy intake with the use of the residual approach. Q, quintile.

<sup>2</sup> Median intake: Q1, 0.68 g/d; Q5, 45.8 g/d.

<sup>3</sup> Median intake: Q1, 39.0 g/d; Q5, 102.7 g/d.

<sup>4</sup> Median intake: Q1, 2.2 g/d; Q5, 9.5 g/d.

<sup>5</sup> Associations with continuous variables were examined with linear regression analysis (generalized linear model) and a test for trend in which subjects in each quintile were assigned the median value of intake. Associations with categorical variables were examined with a chi-square analysis.

<sup>6</sup> Adjusted for sex.

<sup>7</sup>  $\bar{x} \pm SE$  (all such values).

<sup>8</sup> Adjusted for age and sex.

**Table 2**  
Dietary intakes of 1516 men and women participating in the Baltimore Longitudinal Study on Aging at the time of the first visit at which participants had complete dietary data<sup>1</sup>

Nutrient intake	Whole grains <sup>2</sup>			Refined grains <sup>3</sup>			Cereal fiber <sup>4</sup>		
	Q1	Q5	P <sup>5</sup>	Q1	Q5	P <sup>5</sup>	Q1	Q5	P <sup>5</sup>
Energy (kJ) <sup>6</sup>	7932 ± 111 <sup>7</sup>	9125 ± 109	<0.0001	7306 ± 102	9868 ± 102	<0.0001	8879 ± 102	9537 ± 103	<0.0001
Carbohydrate (% of energy) <sup>8</sup>	41.4 ± 0.5	51.7 ± 0.5	<0.0001	43.1 ± 0.65	50.5 ± 0.5	<0.0001	40.1 ± 0.5	52.5 ± 0.5	<0.0001
Protein (% of energy) <sup>8</sup>	16.1 ± 0.2	16.2 ± 0.2	0.29	16.7 ± 0.2	15.2 ± 0.2	<0.0001	16.6 ± 0.2	16.2 ± 0.2	0.84
Total fat (% of energy) <sup>8</sup>	38.9 ± 0.4	32.2 ± 0.4	<0.0001	36.8 ± 0.5	34.3 ± 0.4	<0.0001	39.2 ± 0.4	31.8 ± 0.4	<0.0001
Saturated fat (% of energy) <sup>8</sup>	13.7 ± 0.2	10.8 ± 0.2	<0.0001	12.7 ± 0.2	11.9 ± 0.2	0.001	13.8 ± 0.2	10.8 ± 0.2	<0.0001
Total fiber (g) <sup>8</sup>	13.9 ± 0.5	24.7 ± 0.5	<0.0001	19.8 ± 0.7	18.6 ± 0.5	0.03	14.5 ± 0.5	25.9 ± 0.5	<0.0001
Alcohol (g) <sup>8</sup>	15.6 ± 1.0	8.1 ± 1.1	<0.0001	17.3 ± 1.2	11.2 ± 0.9	<0.0001	17.5 ± 0.9	7.4 ± 0.9	<0.0001
Cholesterol (mg) <sup>8</sup>	224 ± 2	206 ± 2	<0.0001	218 ± 3	218 ± 2	0.08	227 ± 2	203 ± 2	<0.0001
Folate (mg) <sup>8</sup>	315 ± 134	525 ± 13	<0.0001	435 ± 17	380 ± 14	0.33	339 ± 13	531 ± 13	<0.0001
Magnesium (mg) <sup>8</sup>	243 ± 5	382 ± 5	<0.0001	322 ± 7	291 ± 6	<0.001	254 ± 5	397 ± 5	<0.0001
Vitamin E (mg) <sup>8</sup>	24.8 ± 6.1	63.1 ± 5.4	<0.0001	39.7 ± 5.5	30.1 ± 5.4	0.54	26.9 ± 5.5	60.9 ± 5.5	<0.0001
Vitamin B-6 (mg) <sup>8</sup>	3.0 ± 0.4	6.2 ± 0.6	<0.0001	3.7 ± 0.6	3.1 ± 0.6	0.89	3.0 ± 0.6	3.9 ± 0.6	0.20

<sup>1</sup> n = 230 or 231 per quintile (Q).

<sup>2</sup> Median intake: Q1, 0.68 g/d; Q5, 45.8 g/d.

<sup>3</sup> Median intake: Q1, 39.7 g/d; Q5, 102.7 g/d.

<sup>4</sup> Median intake: Q1, 2.2 g/d; Q5, 9.5 g/d.

<sup>5</sup> Associations were examined with linear regression analysis (generalized linear model) and a test for trend in which subjects in each quintile were assigned the median value of intake.

<sup>6</sup> Adjusted for age and sex.

<sup>7</sup>  $\bar{x} \pm SE$  (all such values).

<sup>8</sup> Adjusted for age, sex, and total energy. Intakes from dietary supplements are not included.

**Table 3**  
Chronic disease risk factors according to quintile (Q) of whole-grain intakes among men and women participating in the Baltimore Longitudinal Study of Aging

Risk factor	Whole-grain intake <sup>f</sup>					P for trend
	Q1	Q2	Q3	Q4	Q5	
BMI (kg/m <sup>2</sup> ) [n = 1502]						
Simple adjusted <sup>2</sup>	25.7 ± 0.2 <sup>3</sup>	25.7 ± 0.2	25.0 ± 0.2	24.7 ± 0.2	24.2 ± 0.2	<0.0001
Multivariate adjusted <sup>4</sup>	25.5 ± 0.2	25.7 ± 0.2	25.0 ± 0.2	24.7 ± 0.2	24.8 ± 0.2	<0.0001
Weight (kg) [n = 1502]						
Simple adjusted <sup>2</sup>	75.4 ± 0.7	75.0 ± 0.6	73.8 ± 0.6	72.0 ± 0.6	72.2 ± 0.7	0.0002
Multivariate adjusted <sup>4</sup>	75.0 ± 0.7	75.1 ± 0.6	73.7 ± 0.6	73.0 ± 0.6	72.6 ± 0.7	0.004
Waist circumference (cm) [n = 1404]						
Simple adjusted <sup>2</sup>	87.8 ± 0.6	87.7 ± 0.6	85.8 ± 0.6	85.6 ± 0.6	84.4 ± 0.6	<0.0001
Multivariate adjusted <sup>4</sup>	87.4 ± 0.6	87.6 ± 0.6	85.7 ± 0.6	85.7 ± 0.6	85.0 ± 0.6	0.002
Total cholesterol (mmol/L) [n = 1444]						
Simple adjusted <sup>2</sup>	5.70 ± 0.06	5.64 ± 0.06	5.52 ± 0.06	5.51 ± 0.06	5.49 ± 0.06	0.01
Multivariate adjusted <sup>4,5</sup>	5.71 ± 0.06	5.64 ± 0.05	5.52 ± 0.05	5.50 ± 0.05	5.49 ± 0.06	0.02
HDL cholesterol (mmol/L) [n = 1029]						
Simple adjusted <sup>2</sup>	1.26 ± 0.02	1.27 ± 0.02	1.29 ± 0.02	1.25 ± 0.02	1.23 ± 0.02	0.25
Multivariate adjusted <sup>4,5</sup>	1.27 ± 0.02	1.28 ± 0.02	1.29 ± 0.02	1.25 ± 0.02	1.22 ± 0.02	0.07
LDL cholesterol (mmol/L) [n = 1025]						
Simple adjusted <sup>2</sup>	3.15 ± 0.06	3.00 ± 0.06	2.98 ± 0.06	2.97 ± 0.06	3.00 ± 0.06	0.14
Multivariate adjusted <sup>4,5</sup>	3.16 ± 0.06	3.02 ± 0.06	2.99 ± 0.06	2.98 ± 0.06	2.96 ± 0.06	0.04
Triacylglycerols (mmol/L) [n = 1430]						
Simple adjusted <sup>2</sup>	1.26 ± 0.04	1.30 ± 0.04	1.20 ± 0.04	1.15 ± 0.04	1.12 ± 0.05	0.005
Multivariate adjusted <sup>4,5</sup>	1.23 ± 0.05	1.25 ± 0.05	1.21 ± 0.05	1.18 ± 0.05	1.16 ± 0.05	0.22
Diastolic blood pressure (mm Hg) [n = 1464]						
Simple adjusted <sup>2</sup>	79.8 ± 0.6	80.8 ± 0.5	78.2 ± 0.5	80.6 ± 0.5	79.1 ± 0.6	0.04
Multivariate adjusted <sup>4,6</sup>	79.8 ± 0.6	80.8 ± 0.6	78.2 ± 0.6	80.6 ± 0.6	79.2 ± 0.7	0.42
Systolic blood pressure (mm Hg) [n = 1464]						

Risk factor	Whole-grain intake <sup>1</sup>					P for trend
	Q1	Q2	Q3	Q4	Q5	
Simple adjusted <sup>2</sup>	130.9 ± 1.1	130.7 ± 1.1	125.6 ± 1.1	130.6 ± 1.1	127.8 ± 1.1	0.12
Multivariate adjusted <sup>4,6</sup>	129.2 ± 1.0	130.0 ± 0.9	126.9 ± 0.9	131.1 ± 0.9	128.3 ± 1.0	0.79
Fasting glucose (mmol/L) [n = 1324]						
Simple adjusted <sup>2</sup>	5.52 ± 0.06	5.62 ± 0.06	5.51 ± 0.06	5.45 ± 0.06	5.48 ± 0.06	0.21
Multivariate adjusted <sup>4,7</sup>	5.49 ± 0.06	5.58 ± 0.06	5.51 ± 0.06	5.51 ± 0.06	5.49 ± 0.06	0.57
2-h Glucose (mmol/L) [n = 882]						
Simple adjusted <sup>2</sup>	8.34 ± 0.18	7.62 ± 0.18	7.66 ± 0.18	7.79 ± 0.18	7.32 ± 0.18	0.002
Multivariate adjusted <sup>4,7</sup>	8.24 ± 0.17	7.59 ± 0.16	7.63 ± 0.16	7.94 ± 0.16	7.32 ± 0.17	0.006
Fasting insulin (mmol/L) [n = 460]						
Simple adjusted <sup>2</sup>	74.5 ± 4.0	70.5 ± 3.9	72.2 ± 3.9	72.1 ± 3.9	68.9 ± 4.0	0.41
Multivariate adjusted <sup>4,7</sup>	71.6 ± 3.9	70.0 ± 3.7	73.4 ± 3.7	71.3 ± 3.7	71.8 ± 4.1	0.90
2-h Insulin (mmol/L) [n = 455]						
Simple adjusted <sup>2</sup>	534 ± 39.2	399 ± 38.8	357 ± 38.8	417 ± 38.8	381 ± 39.2	0.04
Multivariate adjusted <sup>4,7</sup>	479 ± 38.0	416 ± 36.0	360 ± 35.7	421 ± 35.7	414 ± 39.1	0.43

<sup>1</sup> Quintiles were developed separately for each outcome because of differences in sample sizes. Median values for Q1 and Q5 were as follows: BMI and weight, 0.65 and 46.0 g/d, respectively; waist circumference, 0.94 and 49.3 g/d, respectively; total cholesterol, 0.63 and 45.6 g/d, respectively; HDL cholesterol, 4.1 and 54.0 g/d, respectively; LDL cholesterol and triacylglycerols, 3.9 and 54.8 g/d, respectively; blood pressure, 0.62 and 45.4 g/d, respectively; fasting glucose, 0.56 and 45.4 g/d, respectively; 2-h glucose, 1.1 and 50.6 g/d, respectively; fasting insulin, 2.2 and 51.5 g/d, respectively; 2-h insulin, 2.4 and 51.7 g/d, respectively.

<sup>2</sup> Adjusted for age, sex, total energy, and decade of visit.

<sup>3</sup>  $\bar{x} \pm$  SEM (all such values) estimated with least-squares means from a linear regression analysis (generalized linear model).

<sup>4</sup> Adjusted for age, sex, total energy, decade of visit, race, education, vitamin supplement use, smoking, and percentage of energy from saturated fat, alcohol, and refined grains.

<sup>5</sup> With additional adjustment for BMI, use of lipid-lowering medication, and hypercholesterolemia.

<sup>6</sup> With additional adjustment for BMI, use of blood pressure-lowering medication, and hypertension.

<sup>7</sup> With additional adjustment for BMI, use of oral hypoglycemic medication, and diabetes.

**Table 4**  
Chronic disease risk factors according to quintile (Q) of cereal fiber intake at the time of the first visit among men and women participating in the Baltimore Longitudinal Study of Aging

Risk factor	Cereal fiber intake <sup>f</sup>					P for trend
	Q1	Q2	Q3	Q4	Q5	
BMI (kg/m <sup>2</sup> ) [n = 1502]						
Simple adjusted <sup>2</sup>	25.9 ± 0.2 <sup>3</sup>	25.3 ± 0.2	24.4 ± 0.2	24.8 ± 0.2	24.1 ± 0.2	<0.0001
Multivariate adjusted <sup>4</sup>	25.7 ± 0.2	25.2 ± 0.2	24.3 ± 0.2	24.8 ± 0.2	24.3 ± 0.2	<0.0001
Weight (kg) [n = 1502]						
Simple adjusted <sup>2</sup>	76.0 ± 0.6	74.3 ± 0.6	74.4 ± 0.6	73.4 ± 0.6	71.4 ± 0.7	<0.0001
Multivariate adjusted <sup>4</sup>	75.6 ± 0.7	74.1 ± 0.6	74.3 ± 0.6	73.0 ± 0.6	71.4 ± 0.8	0.0004
Waist circumference (cm) [n = 1404]						
Simple adjusted <sup>2</sup>	87.9 ± 0.6	87.2 ± 0.6	87.1 ± 0.6	85.7 ± 0.6	83.5 ± 0.6	<0.0001
Multivariate adjusted <sup>4</sup>	87.4 ± 0.6	86.9 ± 0.6	87.0 ± 0.6	86.0 ± 0.6	84.1 ± 0.6	<0.0001
Total cholesterol (mmol/L) [n = 1444]						
Simple adjusted <sup>2</sup>	5.73 ± 0.06	5.61 ± 0.06	5.53 ± 0.06	5.57 ± 0.06	5.43 ± 0.07	0.001
Multivariate adjusted <sup>4,5</sup>	5.73 ± 0.06	5.60 ± 0.06	5.51 ± 0.06	5.57 ± 0.06	5.44 ± 0.06	0.005
HDL cholesterol (mmol/L) [n = 1029]						
Simple adjusted <sup>2</sup>	1.23 ± 0.02	1.28 ± 0.02	1.28 ± 0.02	1.25 ± 0.02	1.26 ± 0.02	0.91
Multivariate adjusted <sup>4,5</sup>	1.23 ± 0.02	1.30 ± 0.02	1.27 ± 0.02	1.25 ± 0.02	1.25 ± 0.02	0.59
LDL cholesterol (mmol/L) [n = 1025]						
Simple adjusted <sup>2</sup>	3.11 ± 0.06	3.07 ± 0.06	3.00 ± 0.06	2.91 ± 0.06	3.00 ± 0.06	0.09
Multivariate adjusted <sup>4,5</sup>	3.13 ± 0.06	3.07 ± 0.06	3.01 ± 0.06	2.90 ± 0.06	2.99 ± 0.06	0.07
Triacylglycerols (mmol/L) [n = 1430]						
Simple adjusted <sup>2</sup>	1.27 ± 0.05	1.28 ± 0.04	1.18 ± 0.04	1.20 ± 0.04	1.11 ± 0.05	0.04
Multivariate adjusted <sup>4,5</sup>	1.24 ± 0.05	1.26 ± 0.04	1.16 ± 0.04	1.23 ± 0.04	1.15 ± 0.05	0.12
Diastolic blood pressure (mm Hg) [n = 1464]						
Simple adjusted <sup>2</sup>	80.8 ± 0.7	80.7 ± 0.7	79.4 ± 0.7	79.6 ± 0.7	77.8 ± 0.8	0.009
Multivariate adjusted <sup>4,6</sup>	79.5 ± 0.8	79.8 ± 0.6	79.1 ± 0.7	80.8 ± 0.7	79.2 ± 0.8	0.90
Systolic blood pressure (mm Hg) [n = 1464]						



Risk factor	Cereal fiber intake <sup>1</sup>					P for trend
	Q1	Q2	Q3	Q4	Q5	
Simple adjusted <sup>2</sup>	130.8 ± 1.1	130.1 ± 1.1	128.1 ± 1.0	128.9 ± 1.1	127.6 ± 1.1	0.06
Multivariate adjusted <sup>4,6</sup>	128.7 ± 1.0	129.0 ± 0.9	127.7 ± 0.9	130.6 ± 0.9	129.7 ± 1.0	0.27
Fasting glucose (mmol/L) [n = 1324]						
Simple adjusted <sup>2</sup>	5.64 ± 0.06	5.49 ± 0.06	5.54 ± 0.06	5.44 ± 0.06	5.47 ± 0.06	0.12
Multivariate adjusted <sup>4,7</sup>	5.55 ± 0.05	5.48 ± 0.05	5.53 ± 0.05	5.49 ± 0.05	5.52 ± 0.05	0.95
2-h Glucose (mmol/L) [n = 882]						
Simple adjusted <sup>2</sup>	8.23 ± 0.18	8.03 ± 0.18	7.63 ± 0.18	7.44 ± 0.18	7.40 ± 0.18	0.0008
Multivariate adjusted <sup>4,7</sup>	8.05 ± 0.21	7.94 ± 0.20	7.72 ± 0.19	7.55 ± 0.20	6.48 ± 0.21	0.02
Fasting insulin (mmol/L) [n = 460]						
Simple adjusted <sup>2</sup>	70.1 ± 4.0	73.6 ± 3.9	72.4 ± 3.9	71.5 ± 4.0	70.6 ± 4.0	0.60
Multivariate adjusted <sup>4,7</sup>	68.9 ± 4.	72.2 ± 3.8	73.0 ± 3.7	71.3 ± 3.8	73.0 ± 4.0	0.68
2-h Insulin (mmol/L) [n = 455]						
Simple adjusted <sup>2</sup>	492 ± 39.5	469 ± 38.9	387 ± 38.7	366 ± 39.3	374 ± 39.1	0.02
Multivariate adjusted <sup>4,7</sup>	438 ± 38.8	477 ± 36.2	404 ± 35.8	356 ± 36.3	413 ± 38.2	0.33

<sup>1</sup> Quintiles were developed separately for each outcome because of differences in sample sizes. Values for Q1 and Q5 were as follows: BMI and weight, 2.19 and 9.51 g/d, respectively; waist circumference, 2.31 and 9.74 g/d, respectively; total cholesterol, 2.20 and 9.56 g/d, respectively; HDL and LDL cholesterol, 2.90 and 11.49 g/d, respectively; triacylglycerols, 2.20 and 9.58 g/d, respectively; blood pressure, 2.19 and 9.43 g/d, respectively; fasting glucose, 2.27 and 9.67 g/d, respectively; 2-h glucose, 2.39 and 10.42 g/d, respectively; fasting insulin and 2-h insulin, 2.54 and 11.63 g/d, respectively.

<sup>2</sup> Adjusted for age<sup>2</sup>, sex, total energy, and decade of visit.

<sup>3</sup>  $\bar{x} \pm \text{SEM}$  (all such values) estimated with least-squares means from a linear regression analysis (generalized linear model).

<sup>4</sup> Adjusted for age<sup>2</sup>, sex, total energy, decade of visit, race, education, vitamin supplement use, smoking, and percentage of energy from saturated fat and alcohol.

<sup>5</sup> With additional adjustment for BMI, use of lipid-lowering medication, and hypercholesterolemia.

<sup>6</sup> With additional adjustment for BMI, use of blood pressure-lowering medication, and hypertension.

<sup>7</sup> With additional adjustment for BMI, use of oral hypoglycemic medication, and diabetes.