Dietary Fiber, Weight Gain, and Cardiovascular Disease Risk Factors in Young Adults

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ABSTRACT

Context Dietary composition may affect insulin secretion, and high insulin levels, in turn, may increase the risk for cardiovascular disease (CVD).

Objective To examine the role of fiber consumption and its association with insulin levels, weight gain, and other CVD risk factors compared with other major dietary components.

Design and Setting The Coronary Artery Risk Development in Young Adults (CARDIA) Study, a multicenter population-based cohort study of the change in CVD risk factors over 10 years (1985-1986 to 1995-1996) in Birmingham, Ala; Chicago, Ill; Minneapolis, Minn; and Oakland, Calif.

Participants A total of 2909 healthy black and white adults, 18 to 30 years of age at enrollment.

Main Outcome Measures Body weight, insulin levels, and other CVD risk factors at year 10, adjusted for baseline values.

Results After adjustment for potential confounding factors, dietary fiber showed linear associations from lowest to highest quintiles of intake with the following: body weight (whites: 174.8-166.7 lb [78.9-75.0 kg], P<.001; blacks: 185.6-177.6 lb [83.5-79.9 kg], P=.001), waist-to-hip ratio (whites: 0.813-0.801, P=.004; blacks: 0.809-0.799, P=.05), fasting insulin adjusted for body mass index (whites: 261.1-234.7 pmol/L [37.6-33.8 µU/mL], P=.03; blacks: 370.2-259.7 pmol/L [53.3-37.4 µU/mL], P=.001). Fiber was also associated with blood pressure and levels of triglyceride, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and fibrinogen; these associations were substantially attenuated by adjustment for fasting insulin level. In comparison with other major dietary components, fiber consumption predicted insulin levels, weight gain, and other CVD risk factors more strongly than did total or saturated fat consumption. High-fiber diets may protect against obesity and CVD by lowering insulin levels.

Conclusions Fiber consumption predicted insulin levels, weight gain, and other CVD risk factors more strongly than did total or saturated fat consumption. High-fiber diets may protect against obesity and CVD by lowering insulin levels. The prevalence of cardiovascular disease (CVD), after declining steadily since mid-century, has been stable or increasing over the past decade. Indeed, CVD continues to be the leading cause of death in the United States.2 Factors known to increase the risk of CVD include age, obesity, central distribution of body fat, smoking, physical inactivity, hypertension, dyslipidemias, and abnormalities in blood clotting factors. Insulin resistance associated with hyperinsulinemia is common to many of these risk factors.

Because of the critical role of insulin in glucose homeostasis, resistance to insulin-stimulated glucose uptake usually induces compensatory hyperinsulinemia. Fasting insulin level is, in fact, an excellent marker for insulin resistance in population studies.3 While this compensatory process serves to maintain glucose tolerance, chronic hyperinsulinemia may increase risk for CVD through a variety of mechanisms.4,5

Obesity, smoking, age, and physical inactivity may cause insulin resistance and hyperinsulinemia, but...
together appear to account for, at most, 50% of the observed individual variability. This finding raises the important question as to what other factors contribute to hyperinsulinemia and, by implication, CVD.

Diet may affect insulin levels in 3 ways: by modulating insulin secretion, by affecting insulin action at peripheral sites, or by promoting obesity. Total or saturated fat intake has been reported to act in each of these ways, but the magnitude and significance of these effects continue to be debated. Moreover, both total and saturated fat intake, as a percentage of total energy consumption, have been declining since the 1960s, although myocardial infarction incidence has been stable in the past decade. Similarly, the effects of dietary carbohydrate on insulin sensitivity are controversial.

Several lines of evidence suggest that dietary fiber may play a key role in the regulation of circulating insulin levels. Dietary fiber reduces insulin secretion by slowing the rate of nutrient absorption following a meal. Experimentally, insulin sensitivity increases and body weight decreases on high-fiber diets. In addition, epidemiological analyses have suggested that fiber protects against hypertension, hyperlipidemia, and CVD.

The purpose of this study was to test the hypothesis that fiber consumption is independently and inversely associated with insulin levels, weight gain, and other CVD risk factors among adults, and to compare fiber with fat and other major dietary components.

METHODS

The Coronary Artery Risk Development in Young Adults (CARDIA) Study is a multicenter population-based study of CVD risk factor evolution in young adults in 4 US areas—Birmingham, Ala; Chicago, Ill; Minneapolis, Minn; and Oakland, Calif. Stratification was used to obtain nearly equal numbers of blacks and whites, younger (18-24 years) and older (25-30 years) individuals, and those with more (>high school) and less (≤high school) education. A total of 5111 (51% of eligible participants) attended the baseline examination (year 0) in 1985-1986, with higher participation rates for men, whites, and highly educated individuals. The cohort has been followed for 10 years to date, with follow-up examinations at years 2 (1987-1988), 5 (1990-1991), 7 (1992-1993), and 10 (1995-1996).

A total of 3609 participants attended the year 0, 7, and 10 clinic examinations and completed the diet history at year 7. In accord with previous CARDIA articles, we excluded individuals with extreme values of dietary intake (<3347 and >33,472 kJ/d [<800 and >8000 kcal/d] for men and <2510 and >25,104 kJ/d [<600 and >6000 kcal/d] for women; n = 101). We then hierarchically excluded women who were lactating or pregnant at the baseline examination or within 180 days of the year 10 examination (n = 222), individuals having diabetes (use of medications to control blood glucose or a fasting blood glucose concentration of >7.77 mmol/L [140 mg/dL]) at examination years 0 or 10 (n = 64), individuals taking medication for blood pressure or lipid control (for analyses of fasting and 2-hour insulin, blood pressure, triglycerides, high-density lipoprotein cholesterol [HDL-C], and low-density lipoprotein cholesterol [LDL-C]; n = 129), and those who had not fasted for at least 8 hours prior to the clinic visit (for analyses of levels of fasting and 2-hour insulin, triglycerides, HDL-C, and LDL-C; n = 331). As a result of these exclusions and missing data (omitted rather than imputed) for covariates or dependent variables, the final sample size available for these analyses varied from 1801 (2-hour insulin) to 2909 (body weight).

Most CVD risk factors used as dependent variables here were measured at all CARDIA examinations. To model risk factors prospectively over the maximum time period that the cohort has been observed, dependent variables were taken from the year 10 examination and adjusted for year 0 values (except 2-hour insulin, which was available at year 10 only, and fibrinogen, which was available at year 5 only). Diet, as described below, was measured at years 0 and 7. At the time that year 0 dietary data were collected, the nutrient database reported only crude fiber values and the overall fiber database was incomplete. By the time of the year 7 data collection, the database included total dietary fiber for all entries. For this reason, diet from year 7 was used for the independent variables for these analyses, reflecting the most accurate dietary assessment of this population.

The CARDIA diet history is an interviewer-administered quantitative food frequency questionnaire including approximately 700 foods. Sex- and energy-adjusted 1-month test-retest correlations of macronutrients tended to be lower for blacks (0.27-0.58) than whites (0.54-0.82). Validity correlations between mean daily nutrient intakes from the CARDIA diet history and means from 7 randomly scheduled 24-hour recalls ranged from 0.50 to 0.86 in white men to 0.04 to 0.53 in black women. The University of Minnesota Nutrition Coordinating Center nutrient database was used to estimate nutrient intake (NCC Nutrient Database, Version 20, October 1991, Nutrition Coordinating Center, University of Minnesota, Minneapolis). Dietary and nutrient measures from the CARDIA diet history used in these analyses included energy intake (kJ/d), alcohol intake (mL/d), dietary fiber (g/4184 kJ/d, according to the Association of Official Analytical Chemists, United States Department of Agriculture, Human Nutrition Information Service, Gaithersburg, Md, 1988), and percentage of daily energy intake from saturated fats, unsaturated (monounsaturated plus polyunsaturated) fats, carbohydrates (excluding dietary fiber), and protein.

Prior to each examination, participants were asked to fast for 12 hours and to avoid smoking and heavy physical activity for 2 hours. Blood pressure was obtained prior to other clinical procedures with a
standardized random-zero mercury sphygmomanometer (W. A. Baum Co, Copaigue, NY). Body weight (to the nearest 0.2 kg with a calibrated balance beam scale) and height (to the nearest 0.5 cm with a vertical ruler) were measured with subjects standing and dressed in light clothing without shoes. Body mass index (BMI) was computed as weight in kilograms divided by height in meters squared. Waist and hip circumferences were measured with a tape to the nearest 0.5 cm around the minimal abdominal girth and the maximal protrusion of the hips at the level of the pubic symphysis, respectively.

The insulin radioimmunoassay required an overnight, equilibrium incubation and used a unique antibody that has less than 0.2% cross-reactivity to human proinsulin and its primary circulating split form Des 31,32 proinsulin (Linco Research, St Louis, Mo). Northwest Lipid Research Clinic Laboratory (Seattle, Wash), which is a participant in the Centers for Disease Control and Prevention standardization program, was used to measure all lipids. Triglyceride levels were estimated using enzymatic procedures, and HDL-C levels were measured according to the method of Warnick et al. Low-density lipoprotein cholesterol levels were calculated with the formula devised by Friedewald et al for individuals with triglyceride concentrations less than 4.52 mmol/L (400 mg/dL). Fibrinogen analysis was performed at the University of Vermont Thrombosis Center (Burlington) by clot formation rate using a semiautomated modification of the Clauss method. To determine stimulated insulin levels, subjects drank a carbonated solution containing 75 g of dextrose after an overnight fast. Blood was obtained 2 hours later and assayed as described above.

We used SAS software (release 6.12, SAS Institute, Cary, NC) for all statistical analyses. Race-specific general linear models were computed to adjust least squares means of CVD risk factors (dependent variables) according to quintiles of dietary factors (independent variables). Quintile cutpoints for dietary factors were based on distributions of the entire cohort, resulting in similar levels of intake between blacks and whites within each quintile. Although the number of blacks and whites were not evenly distributed across quintiles, no quintile for any dietary factor contained less than 84 individuals of either race. Dependent variables were body weight; waist-to-hip ratio; systolic and diastolic blood pressure; HDL-C; LDL-C; fibrinogen; and the natural logarithms (to generate a near-normal distribution) of fasting insulin, 2-hour insulin, and triglycerides. To express insulin (pmol/L [µU/mL]) and triglyceride (mmol/L [mg/dL]) concentrations according to their natural scale, geometric means were computed by exponentiating the adjusted least squares means. Covariates included in the models as potential confounders were age, sex, CARDIA field center, education (high school graduate vs < high school graduate at year 7), energy intake (kJ/d [kcal/d] at year 7), vitamin supplementation use (yes/no at year 7), cigarette smoking (classified as never, former, quitter, starter, or current at years 0 and 10), alcohol intake (mean mL/d at years 0, 7, and 10), and total physical activity (mean units at years 0 and 7). Since obesity causes insulin resistance and hyperinsulinemia, we also adjusted the associations between dietary components and insulin levels for BMI (mean of years 0 and 10). To examine whether the associations between dietary components and risk factors may be mediated by insulin level, we adjusted for fasting insulin in additional models. Joint associations of dietary fiber and total fat with 10-year weight gain were modeled as the interaction of the tertile distributions for these dietary components (resulting in 9 least squares means) with terms for their main effects included in the models.

For presentation, only the lowest and highest quintiles of dietary intake are shown in the tables; however, graded linear trends were generally observed across all 5 quintiles for those associations that were statistically significant (data not shown). A linear trend across quintiles was tested with contrast statements using orthogonal polynomial coefficients. In separate models, interaction terms between sex and the dietary factors were entered to determine if associations were generally similar between men and women within each race. Of 20 possible interactions with sex between the risk factors and the 6 dietary components, only 4 had P values of < .05 (fiber, total fat, and unsaturated fat with fasting insulin in blacks [all more strongly associated in men (P < .02) than women (P > .18)] and carbohydrate with LDL-C in whites). Six interactions would be expected by chance alone, an observation that justifies pooling men and women within race.

RESULTS

Table 1 shows energy- and sex-adjusted descriptive characteristics of the CARDIA cohort according to lowest and highest quintiles of the dietary factors. Associations with age were positive for fiber, inverse for carbohydrate, weak for fat, and null for protein. Women consumed more fiber and carbohydrate but less protein and fat (whites only) than men. Cigarette smoking was inversely associated with carbohydrate and fiber intake and positively associated with fat intake (whites only). Physical activity was inversely associated with dietary fat, but positively associated with fiber, carbohydrate, and protein. Alcohol intake showed inverse associations with dietary carbohydrate and dietary fat. Finally, vitamin supplementation use was positively associated with dietary fiber, carbohydrate (whites only), and protein, and inversely associated with dietary fat.

**Table 1. Demographic and Behavioral Characteristics**
Mean body weight and waist-to-hip ratio at year 10, adjusted for baseline values, demographic characteristics, and lifestyle behaviors, are shown in Table 2 according to lowest and highest quintiles of dietary intake. Body weight was inversely associated with fiber and carbohydrate and positively associated with protein intake in whites. The mean difference in body weight across quintiles for fiber was considerably larger (−3.65 kg [8.1 lb], \( P < .001 \)) than for carbohydrate (−1.40 kg [3.1 lb], \( P = .04 \)) or protein (+2.03 kg [4.5 lb], \( P < .001 \)). Neither total nor saturated fat intake was associated with body weight in whites. In blacks, dietary fiber was also strongly associated with body weight (−3.60 kg [8.0 lb], \( P = .001 \)), while total fat (+1.62 kg [3.6 lb], \( P = .03 \)) and carbohydrate (−1.58 kg [3.5 lb], \( P = .03 \)) were more modestly associated.

Table 2. Adjusted Means of Year 10 Body Weight, Waist-to-Hip Ratio, Fasting Insulin, and 2-Hour Insulin According to Quintiles of Dietary Factors*

In models including pairs of dietary components (not shown), fiber remained independently associated with body weight after adjustment for carbohydrate (−3.56 kg [7.9 lb], \( P < .001 \)) or protein (−3.65 kg [8.1 lb], \( P < .001 \)) in whites, and fat (−3.24 kg [7.2 lb], \( P < .001 \)) or carbohydrate (−3.33 kg [7.4 lb], \( P = .004 \)) in blacks. In contrast, the associations of body weight with carbohydrate in whites (−1.04 kg [2.3 lb], \( P = .14 \)) and blacks (−0.81 kg [1.8 lb], \( P = .184 \)), and with fat in blacks (+0.50 kg [1.1 lb], \( P = .41 \)) were substantially attenuated by adjustment for fiber.

We also examined the independent and joint associations of fiber and fat intake with 10-year weight gain in white and black men and women (Figure 1). At all levels of fat intake, individuals eating the most fiber gained less weight than those eating the least fiber. In whites, the largest mean difference was found when comparing those with the lowest fiber and fat consumption to those with the greatest fiber and fat consumption (0.59 kg vs 5.72 kg [21.3 vs 12.7 lb], \( P = .003 \)). Fiber intake was significantly associated with waist-to-hip ratio in whites (0.813–0.801, \( P = .004 \)) and blacks (0.809–0.799, \( P = .05 \)), although dietary fat was not (Table 2).

Figure. Joint Associations of Dietary Fiber and Total Fat With 10-Year Weight Gain

Data are adjusted for sex, age, education, energy intake, physical activity, cigarette smoking, alcohol intake, and baseline body weight. To convert pounds (lb) to kilograms (kg), multiply by 0.45.

As shown in Table 2, after adjusting for BMI and other confounding variables, both dietary fiber (mean difference of −5.6 pmol/L [0.8 µU/mL], \( P = .007 \)) and saturated fat (+4.2 pmol/L [0.6 µU/mL], \( P = .03 \)) were associated with fasting insulin in whites. When included in the same
model, fiber remained significantly associated with fasting insulin (−4.2 pmol/L [0.6 µU/mL], P = .03) whereas fat did not (+1.4 pmol/L [0.2 µU/mL], P = .38) (not shown). In blacks, fiber was the only dietary factor associated with fasting insulin level (−9.7 pmol/L [1.4 µU/mL], P = .01). Fiber, but neither total nor saturated fat, was associated with 2-hour insulin in both races (whites: −26.4 pmol/L [3.8 µU/mL], P = .03; blacks: −110.4 pmol/L [15.9 µU/mL], P < .001).

In white men and women, fiber was associated with systolic blood pressure (mean difference from lowest to highest quintiles: −2.2 mm Hg, P = .01), diastolic blood pressure (−2.7 mm Hg, P < .001), triglycerides (−0.09 mmol/L [8 mg/dL], P = .03), HDL-C (+0.06 mmol/L [2.5 mg/dL], P = .003), LDL-C (−0.12 mmol/L [4.8 mg/dL], P = .06), and fibrinogen (−0.47 pmol/L [16 mg/dL], P = .005) (Table 2). With the exception of diastolic blood pressure, these associations were substantially attenuated after adjustment for fasting insulin (systolic blood pressure: −1.2 mm Hg, P = .16; triglycerides: −0.007 mmol/L [0.6 mg/dL], P = .95; HDL-C: +0.033 mmol/L [1.3 mg/dL], P = .10; LDL-C: −0.111 mmol/L [4.3 mg/dL], P = .35; and fibrinogen: −0.21 µmol/L [7.2 mg/dL], P = .38). In contrast, no form of dietary fat was significantly associated with any of these CVD risk factors. Dietary components generally correlated poorly with blood pressure and levels of lipids and fibrinogen in blacks; however, the direction of association was the same for each risk factor in blacks and whites for dietary fiber only.

### Table 3. Adjusted Means of Year 10 Blood Pressure, Triglycerides, High-Density Lipoprotein (HDL) Cholesterol, Low-Density Lipoprotein (LDL) Cholesterol, and Year 5 Fibrinogen According to Quintiles of Dietary Factors

<table>
<thead>
<tr>
<th>Dietary Factor*</th>
<th>Cholesterol</th>
<th>Triglycerides</th>
<th>HDL-C</th>
<th>LDL-C</th>
<th>Fibrinogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest Quintile</td>
<td>5.2 mmol/L</td>
<td>1.7 mmol/L</td>
<td>1.6 mmol/L</td>
<td>3.5 mmol/L</td>
<td>0.3 µmol/L</td>
</tr>
<tr>
<td>Middle Quintile</td>
<td>5.4 mmol/L</td>
<td>1.8 mmol/L</td>
<td>1.7 mmol/L</td>
<td>3.6 mmol/L</td>
<td>0.4 µmol/L</td>
</tr>
<tr>
<td>Highest Quintile</td>
<td>5.6 mmol/L</td>
<td>1.9 mmol/L</td>
<td>1.8 mmol/L</td>
<td>3.7 mmol/L</td>
<td>0.5 µmol/L</td>
</tr>
</tbody>
</table>

**COMMENT**

The prevalence of CVD remains high in the United States despite reductions in total and saturated fat intake to levels near government recommendations. Furthermore, the rates of obesity and type 2 diabetes have increased dramatically, raising serious concern for public health in the next century. While many factors undoubtedly contribute to this problem, our study underscores the potential importance of dietary fiber to CVD risk. These findings are consistent with the Health Professionals’ Follow-up Study in which the modest associations between dietary fat and myocardial infarction incidence were largely attenuated by adjustment for dietary fiber, whereas dietary fiber remained significantly associated with myocardial infarction incidence even after adjustment for saturated fat.

We believe that the strong inverse associations between dietary fiber and multiple CVD risk factors—excessive weight gain, central adiposity, elevated blood pressure, hypertriglyceridemia, low HDL-C, high LDL-C, and high fibrinogen—are mediated, at least in part, by insulin levels. Dietary fiber exerts a major effect on the glycemic, and therefore the insulinemic, response to carbohydrate in a meal. Fiber was shown, for example, to account for about 40% of the variance in glycemic index (a measure of the rate of carbohydrate absorption) among starchy foods. Due to its inherently high glycemic index, a low-fiber diet would tend to stimulate relatively more insulin secretion than a high-fiber diet. In this study, the highest insulin levels after adjustment for BMI were indeed found among individuals with the lowest fiber intake.

High circulating insulin levels, in turn, may cause hypertension, dyslipidemia, abnormalities in blood clotting factors, and perhaps direct vascular injury, components of the so-called syndrome X. Moreover, a recent meta-analysis of 12 prospective studies concluded that insulin concentration had a positive and statistically significant association with CVD incidence. However, methodological inconsistencies among studies preclude an estimate of the magnitude of this association. Recently, a nested case-control study of ischemic heart disease revealed that individuals with fasting insulin concentrations above the median level had 5.5 times the odds of developing heart disease than those without elevated insulin levels after controlling for age, lifestyle factors, BMI, systolic blood pressure, medication use, and family history of heart disease. In this study, fasting insulin level was found to attenuate the associations between fiber and blood pressure, lipids, and fibrinogen, which provides support for an intermediary role of insulin.

The association between dietary fiber and body weight is of particular interest. The high insulin levels associated with low-fiber diets may promote excessive weight gain by several mechanisms, involving alterations in adipose tissue physiology, shunting of metabolic fuels from oxidation to storage, and increased appetite. For example, prior insulin treatment of normal rats increased insulin-stimulated...
glucose utilization in white adipose tissue, but decreased utilization in muscle. These changes were associated with increased food intake and weight gain. In humans, high glycemic index meals have been shown to induce a sequence of acute hormonal changes that diminish availability of metabolic fuels in the postabsorptive period and cause overeating. Indeed, hyperinsulinemia has been associated with excessive weight gain in some, but not all, prospective epidemiological studies. Interestingly, white men and women consuming diets presumed to be lowest in glycemic index (high fiber, high fat) gained the least weight gain in some, but not all, prospective epidemiological studies. Interestingly, white men and women consuming diets presumed to be lowest in glycemic index (high fiber, high fat) gained the least weight gain, whereas those consuming diets presumed to be highest in glycemic index (low fiber, low fat) gained the most during this period.

While fiber may also influence body weight by mechanisms independent of insulin (ie, the low energy density of fiber promoting satiety and decreased weight gain), such alternative explanations cannot fully account for our findings. Were energy density to be of primary importance, fat consumption should be tightly associated with body weight; consistent with some but not all previous studies, we found no association in whites and a modest association in blacks that was explained by fiber intake. Moreover, fiber remained strongly associated with insulin levels after correction for BMI, suggesting that the higher insulin levels in individuals consuming low-fiber diets did not result from excessive weight gain alone. Thus, fiber may have a dual role in the prevention of hyperinsulinemia by decreasing circulating insulin levels directly and by preventing obesity with its associated insulin resistance, effects that may be especially important for individuals consuming low-fat (and therefore high-carbohydrate) diets.

Several methodological issues should be addressed. First, we recognize that this study, like all observational studies, cannot prove causality. For example, high-fiber and low-fat diets are typically associated with other healthful lifestyle patterns. However, the conclusions reached here are likely to be correct for several reasons: the data have been adjusted for all commonly accepted, potential confounding variables; dietary fiber is related to CVD risk by a plausible physiological mechanism; it seems improbable that reverse causality would apply in the general population (ie, the presence of CVD risk factors caused lower fiber intake); and these results are consistent with numerous studies demonstrating improvements in CVD risk factors on either high-fiber or low glycemic index diets. Second, dietary component (eg, fat) could be less precisely or accurately measured than another, and therefore the relative importance of this component with respect to CVD risk factors could be underestimated. However, this study used a standardized, validated diet history designed specifically to quantitate dietary fat. Third, a relatively large spread was observed in dietary fiber intake among individuals in this study; our findings would not necessarily apply to other populations with different patterns of fiber consumption. Fourth, the discrepancies in diet/CVD risk factor associations between whites and blacks found here probably reflect the lower observed validity of the CARDIA diet history among blacks, although the possibility of actual racial differences remains.

This study did not examine the effects of fiber type (eg, soluble or insoluble), source (eg, whole grain, refined grain, vegetable, or fruit), or form (eg, intact or processed). These variables, together with other biologically active constituents associated with fiber (eg, magnesium, vitamin E), may affect the insulin response to ingested carbohydrate as well as CVD risk in important ways. It remains to be determined whether improvement in certain CVD risk factors observed on diets rich in fruits, vegetables, and whole grains are directly attributable to the high fiber content (and lower glycemic index), to related properties (eg, antioxidants, phytochemicals), or both.

In summary, dietary fiber was inversely associated with insulin levels, weight gain, and other risk factors for CVD in young adults. The findings from this investigation, together with those of the Health Professionals’ Follow-Up Study, raise the interesting possibility that fiber may play a greater role in determining CVD risk than total or saturated fat intake. Long-term interventional studies are needed to examine the effects of high-fiber and low glycemic index diets in the prevention of obesity and CVD.

REFERENCES


