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Cross-sectional association of dietary patterns with insulin resistance phenotypes among adults without diabetes in the Framingham Offspring Study

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Abstract

Cluster analysis is a valuable tool for exploring the health consequences of consuming different dietary patterns. We used this approach to examine the cross-sectional relationship between dietary patterns and insulin resistance phenotypes, including waist circumference, body mass index (BMI), fasting insulin, 2-h post-challenge insulin, insulin sensitivity index ($ISI_{0,120}$), HDL cholesterol, triacylglycerol and blood pressure, using data from the fifth examination cycle of the Framingham Offspring Study. Among 2,875 participants without diabetes, we identified four dietary patterns based on the predominant sources of energy: “Fruits, Reduced Fat Dairy and Whole Grains”, “Refined Grains and Sweets”, “Beer”, and “Soda”. After adjusting for multiple comparisons and potential confounders, compared with the “Fruits, Reduced Fat Dairy and Whole Grains” pattern, the “Refined Grains and Sweets” pattern had significantly higher mean waist circumference (92.4 versus 90.5 cm, P=0.008) and BMI (27.3 versus 26.6 kg/m^2, P=0.02); the “Soda” pattern had significantly higher mean fasting insulin concentration (31.3 versus 28.0 μU/ml, P≤0.001); the “Beer” pattern had significantly higher mean HDL cholesterol concentration (1.46 versus 1.31 mmol/l, P<0.001). No associations were observed between dietary patterns and ISI0,120, triacylglycerol, and systolic or diastolic blood pressure. Our findings suggest that consumption of a diet rich in fruits, vegetables, whole grains and reduced fat dairy protects against insulin resistance phenotypes and displacing these healthy choices with refined grains, high fat dairy, sweet baked foods, candy and sugar sweetened soda promotes insulin resistant phenotypes.

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Keywords

Dietary patterns; cluster analysis; insulin resistance phenotypes; Framingham Offspring Study

Introduction

Insulin resistance is a common pathologic state in which target cells (liver, muscle and adipose tissue) fail to respond to normal levels of circulating insulin [(1)]. Concomitant conditions that are associated with insulin resistance include impaired glucose tolerance, impaired fasting glucose, elevated insulin concentrations, low HDL cholesterol concentrations and elevated triacylglycerol concentrations[(2)]. Diet is believed to play a key role in the development of insulin resistance. To date, various aspects of diet, such as fat, carbohydrate, fiber, whole grains, magnesium, glycemic index and load [(3-7)], have been related to insulin resistance. Most observational studies relate individual nutrients or foods to various outcomes and although these studies contribute to our understanding on the role of diet in disease, there are several potential limitations. First, due to the high correlation between components of a diet, it is often difficult to examine the separate effect for a specific nutrient or food. Second, as interactions may exist between components of a diet, the findings of single nutrient or food analysis may be misleading. Finally, the effect of a single nutrient or food on a disease outcome or risk factor may be too small to detect, particularly in smaller cohorts [(8,9)].

The use of dietary patterns to capture the overall dietary habits of populations has received much attention in recent years. Instead of focusing on the effect of individual nutrients or foods, a dietary pattern approach examines the effect of an overall diet on health outcomes, thereby representing a complex combination of foods and nutrients [(10)]. Thus, from a public health perspective, results from dietary pattern analysis can be easily translated and incorporated into dietary guidelines for public [(9)]. A number of observational studies have examined the association between dietary patterns and either the metabolic syndrome, or components of the metabolic syndrome [(11-16)]. Although insulin resistance is a key underlying risk factor associated with this syndrome, few studies have used a dietary pattern approach to directly examine the relationship between diet and surrogate measures of insulin resistance in healthy adults [(11,17)]. To our knowledge, no studies have evaluated dietary patterns derived by cluster analysis in relation to insulin resistance in a population without diabetic patients. The purpose of this study was to determine if specific dietary patterns derived by cluster analysis are related to insulin resistance phenotypes among adults without diabetes.

Experimental methods

Participants

The present investigation examined the cross-sectional relationship between dietary patterns and insulin resistance phenotypes using data from the Framingham Offspring Study. The Framingham Study was initiated in 1948 as a longitudinal population-based study of cardiovascular disease. In 1971, 5,135 offspring of original participants of Framingham Study and spouses of the offspring were recruited to participate in the Framingham Offspring Study. Members of the Framingham Offspring Study have returned on average every 4 years for a physical examination, questionnaires, laboratory tests, and assessment of cardiovascular and other risk factors [(18)]. During the fifth examination cycle (between 1991 and 1995), a total of 3,799 participants underwent a standardized medical history and physical examination. Valid food frequency questionnaire (FFQ) was available for 3418 participants. Participants were excluded from this analysis if they had previously diagnosed

(n=212) diabetes, or if their fasting glucose concentrations ≥7.0 mmol/l, or 2-h post-challenge glucose concentrations ≥11.1 mmol/l (n=134). We also excluded those who were taking cholesterol-lowing medications (n=197). After exclusions, the final sample size was 2875 participants (1278 men and 1597 women). The institutional review boards for human research at Boston University and Tufts Medical Center reviewed and approved all study protocols and procedures.

Dietary assessment

Usual dietary intake for the previous year was assessed at the fifth examination using a 126-item semi-quantitative FFQ [19]. The questionnaires were mailed to participants before the examination, and the participants were asked to bring the completed questionnaire with them to their examination at the Framingham Heart Study. The FFQ consists of a list foods with a standardized serving size and a selection of nine frequency categories ranging from never or <1 serving/month to >6 servings/day. Separate questions about use of vitamin and mineral supplements and type of breakfast cereal most commonly consumed were also included in the FFQ. FFQ with reported energy intakes less than 2.51 MJ/day (600 Kcal/day) for men and women, or more than 16.74 MJ/day (4,000 Kcal/day) for women or more than 17.57 MJ/day (4,200 Kcal/day) for men, or with more than 12 food items left blank were considered invalid. Nutrient intakes were calculated by multiplying the frequency of consumption of each unit of food from the FFQ by the nutrient content of the specified portion. The relative-validity of the FFQ has been reported for both nutrients and foods [19,20]. Individual foods from the 126-item FFQ were collapsed into 40 food groups based on the similarity of food and nutrient composition (Table 1). Dietary data were used to calculate the average glycemic index of a subject's diet, which is the mean glycemic index of all the food items in the FFQ weighted by the content of carbohydrate from each food item. Dietary Guidelines Adherence Index (DGAI), a measure of adherence to the key dietary intake recommendations in 2005 Dietary Guidelines for Americans, was calculated as a measure of diet quality. The score ranged from 2.5 to 17.5 with a mean of 9.1 in this study population [21].

Outcome measurements

Height, weight, and waist circumference were measured in the standing position by a trained technician. BMI was calculated as weight in kilograms divided by square of height in meters. Blood samples were drawn after the participants had fasted for at least 8 hours for measurement of fasting glucose and insulin, and lipids. A 75-g oral-glucose-tolerance test (OGTT) was administered according to World Health Organization standards to measure the 2-h post-challenge glucose and insulin [22]. Plasma glucose concentrations were measured in fresh specimens with a hexokinase reagent kit (A-gent glucose test, Abbott Laboratories, Inc., South Pasadena, CA); the intra-assay CV was <3%. Plasma insulin concentrations were measured using the Coat-A-Count ^{125}I-radioimmunoassy (Diagnostic Products); this assay has cross-reactivity with proinsulin at the midcurve of 40%, intra-and inter-assay CV of 5-10%. Insulin sensitivity index ($ISI_{0,120}$) was calculated using the following formula [23].

$$ISI_{0,120} = (m/MPG)/\log MSI$$

Where

$m = [75{,}000\ mg + (\text{fasting glucose} - \text{2-h post OGTT glucose}) \times 0.19 \times \text{body weight (kg)}]/120\ min$

MPG is the mean of fasting and 2-h post-OGTT glucose concentrations (mg/dL),

And

MSI is the mean of fasting and 2-h post-OGTT insulin concentrations (mU/L).

Serum lipid measures included enzymatic measurement of triacylglycerol [24] and the measurement of the HDL-cholesterol fraction after precipitation of LDL and VLDL cholesterol with dextran sulfan magnesium [25]. Blood pressure was measured twice after the participants sat for 5 minutes or more.

Covariates

Physical activity was measured using a standardized questionnaire to determine estimates of activity based on a 24-h history. A physical activity score was calculated from the number of hours spent doing specific activities that were categorized (sleep, sedentary, slight activity, moderate activity and heavy activity) and weighted according to oxygen consumption required to perform them (MET-hours/d) [26]. Additional covariate information include age, sex, smoking dose (0, 1-15, 16-25, or >25 cigarettes/d) and years of education.

Statistical analysis

All statistical analyses were performed using Statistical Analysis Systems statistical software package version 9.1 (SAS Institute, Cary, NC, USA). For cluster analysis, the PROC FASTCLUS procedure was used to derive dietary patterns. We used the K-means method to classify participants into a predetermined number of mutually exclusive, non-overlapping groups (clusters) by comparing Euclidean distances between each subject and each cluster center. It aims to minimize the differences within clusters while maximizing the differences between clusters [27,28]. In order to minimize the effect of outliers on the cluster analysis, the FASTCLUS procedure was performed on a predefined number of clusters (n=20). Clusters with less than five persons were removed and the remaining clusters were used as seeds for the subsequent analysis. The analysis was re-run with varying number of clusters, ranging from three to six using the seeds. In addition the analysis was re-run using sex-specific clusters. However, due to the observation of similar clusters in men and women and lack of any significant sex interaction with respect to our current clusters and outcomes, we chose to retain the clusters that included both men and women to maximize statistical power.

The four-cluster set (Table 1) was selected as the final because it provided the most distinct eating patterns. The food groups, represented by the percentage of energy contributed from each food group, were the input variables in the cluster analysis. We decided to treat the food group variables as a percentage of total energy as this helps to remove extraneous variation due to difference in sex, age, body size, and physical activity [29]. The ‘low-calorie soda’ (i.e. diet soda) food group was excluded from cluster analysis because it does not provide energy, leaving 39 food groups for inclusion in the cluster analysis. In each of the clusters defined, daily diet soda consumption was included as servings/d.

To describe food intake across the four clusters (dietary patterns), the age- and sex-adjusted means of energy contribution from each food group were calculated using analysis of covariance (PROC GLM). Analysis of covariance was also used to test differences in nutrient intakes and insulin resistance phenotypes, including waist circumference, BMI, fasting and 2-h post-challenge insulin, $ISI_{0,120}$, HDL cholesterol, triacylglycerol, and systolic and diastolic blood pressure, across the four dietary patterns. Tukey-Kramer's method was used to adjust for the multiple comparisons for all possible pairwise comparisons among the four patterns. Many of the markers of the insulin resistance phenotypes were positively skewed. Consequently, we performed analysis with and without natural logarithmic data transformation for these markers. Since the finding and statistical inference were the same using both the transformed and untransformed data, we present only the results based on the untransformed data to simplified the data presentation. The covariates included age, sex, waist circumference, smoking, physical activity, treatment of

hypertension, and total energy intake. Additional adjustment for education (used to capture socioeconomic status [30]) did not change the results.

In order to examine whether the relationships between dietary patterns and insulin resistance phenotypes were modified by sex or obesity status (BMI ≥ 30 or < 30), we examined first order interactions for each of these associations. Bonferroni adjustment was used to adjust for the multiple comparisons resulting from the examination of these interactions for multiple outcome variables. No statistically significant interactions were observed for any of these outcome variables.

Results

The mean age of study participants was 54 years for both men and women. Men had significantly higher waist circumference (98.5 vs. 85.6 cm, P<0.01), BMI (27.9 vs. 26.3 kg/m^2, P<0.01), physical activity score (36.1 vs. 33.7 Met-hours/d, P<0.01), energy intake (8407 vs. 7306 KJ/d, P<0.01), alcohol intake (15.5 vs. 7.2 g/d, P<0.01), and prevalence of hypertension (19.8% vs.16.1%, P=0.01) than women. There was no difference between men and women with respect to the proportion of smokers (19.4% for men and 19.7% for women).

Four clusters were characterized based on the food or foods that were distinct contributors to total energy intake in each cluster. We named the four clusters as follows; “Fruits, Reduced Fat Dairy and Whole Grains” pattern (n=577), “Refined Grains and Sweets” pattern (n=1846), “Beer” pattern (n=242), and “Soda” pattern (n=210). The “Fruits, Reduced Fat Dairy and Whole Grains” pattern was characterized by relatively higher energy contribution from reduced fat dairy, whole grains, fruits, vegetables, fish and seafood, and lower energy contribution from high fat dairy, meat, chocolate, and sweet baked foods (Table 2). The “Refined Grains and Sweets” pattern was characterized by a relatively high percentage of energy from sweet baked foods (9%) and also contained relatively greater energy contributions from high fat dairy, refined grains, candy. Energy contributions from beer and soda were greatest in the “Beer” and the “Soda” patterns, respectively, and they were the only foods to contribute more than 15% of energy in any of the four patterns. In addition, the “Beer” and “Soda” pattern both had relative lower energy contribution from many healthier food choices, such as reduced fat dairy, fruits, vegetables, fish, whole grains; the “Soda” pattern also had higher contributions from meat, chocolate and miscellaneous sweets. With respect to diet soda consumption, individuals in the “Soda” pattern consumed significantly less diet soda compared to those in the other dietary patterns.

The four dietary patterns differed significantly with respect to sex, nutrient intakes, dietary glycemic index, and diet quality (Table 3). Participants in the “Fruits, Reduced Fat Dairy and Whole Grains” pattern were more likely to be female (67.2%), and participants in the “Beer” pattern were more likely to be male (87.2%). Participants in the “Fruits, Reduced Fat Dairy and Whole Grains” pattern had the lowest total energy intake, lowest energy contribution from total fat and saturated fat, lowest cholesterol intake, highest energy contribution from protein intake, highest intake of dietary fiber, highest intake of potassium, magnesium and calcium, and highest overall diet quality. Individuals in the “Refined Grains and Sweets” pattern had highest energy contribution from total fat, including saturated fat, monounsaturated fat, and polyunsaturated fat, and highest cholesterol intake. Individuals in the “Beer” pattern had the highest alcohol intake, and the lowest energy contribution from carbohydrate and sucrose intakes and glycemic index. Individuals in the “Soda” pattern had the highest energy intake, highest energy contribution from carbohydrate and sucrose, and glycemic index. In addition, this dietary pattern had the lowest energy contribution from

protein; the lowest intakes of fiber, potassium, magnesium and calcium; and the lowest overall diet quality.

Multivariate-adjusted means of insulin resistance phenotype markers were compared across the four dietary patterns (Table 4). Compared to individuals in the “Fruits, Reduced Fat Dairy and Whole Grains” pattern, those in the “Refined Grains and Sweets” pattern had significant higher waist circumference and BMI after adjusting for multiple comparisons and potential confounders, including age, sex, smoking, physical activity, treatment of hypertension and total energy intake. In comparison to individuals in the “Fruits, Reduced Fat Dairy and Whole Grains” pattern, fasting insulin concentrations were significantly higher in those individuals in the “Soda” pattern; In comparison to individuals in the “Fruits, Reduced Fat Dairy and Whole Grains” pattern, HDL cholesterol concentrations were significantly higher among those in the “Beer” pattern. No significant associations were found between dietary pattern and $ISI_{0,120}$, triacylglycerol, or systolic and diastolic blood pressure.

Discussion

In this cross-sectional study of healthy adults in the Framingham Offspring Study, four dietary patterns were derived using cluster analysis (“Fruits, Reduced Fat Dairy and Whole Grains”, “Refined Grains and Sweets”, “Beer”, and “Soda”). The “Refined Grains and Sweets” dietary pattern comprised the largest number of individuals, while the “Soda” pattern comprised the smallest number. The four patterns derived in this study are similar to those identified using cluster analysis in other American populations [31-34]. For example, a Heart Healthy pattern and an Empty Calorie pattern, which resemble our “Fruits, Reduced Fat Dairy and Whole Grains” and “Soda” patterns, were identified as 2 of 6 patterns in women participating at the third examination cycle of the Framingham Offspring Study [33]. Consistent with our study, a Healthy and Alcohol pattern were identified among 5 patterns using cluster analysis in 459 men and women in the Baltimore Longitudinal Study of Aging [32]. Often, an Alcohol pattern is captured in dietary pattern analysis, particularly when men are included in the analysis [32,35,36]. In this study, beer was the predominant contributor to alcohol intake and thus the rational for naming it the beer dietary pattern. Although dietary patterns derived in different studies are assigned different names, they often reflect similar food behaviors and nutrient profiles. For instance, our “Fruits, Reduced Fat Dairy and Whole Grains” pattern is comparable in nutrient content to the ‘dark bread, rice and pasta, vegetables’ pattern identified in the Insulin Resistance Atherosclerosis Study [34] and a ‘milk, cereals, and fruits’ pattern identified among elderly Boston area residents [31].

In this study, compared to individuals in the “Fruits, Reduced Fat Dairy and Whole Grains” dietary pattern, those in the “Refined Grains and Sweets” dietary pattern had significantly higher waist circumference and BMI. The “Refined Grains and Sweets” pattern also had relatively higher energy contribution from high fat dairy, meat, refined grains, sweet baked foods, candy, and had lower energy contribution from reduced fat dairy, fruits, vegetables and whole grains compared to the “Fruits, Reduced Fat Dairy and Whole Grains” pattern. This result is consistent with previous findings that a diet high in refined grains, high fat dairy, meat, sweets, low in whole grains, fruits, vegetables was associated with high risk of obesity [37,38]. Prospective studies also found that consuming a diet high in fruits, vegetables, reduced fat dairy, and whole grains was associated with lower increase in BMI and waist circumference [32,39-42]. In the present study, none of the dietary patterns were associated with improved blood pressure after the exclusion of those on hypertensive medication.

We found individuals in the “Soda” pattern had significantly higher fasting insulin concentrations than those in the “Fruits, Reduced Fat Dairy and Whole Grains” pattern, consistent with our previous finding that consumption of sugar-sweetened drinks is positively associated with fasting insulin [43]. Individuals in the “Soda” pattern also had lower dietary fiber intake, higher dietary glycemic index. The protective effect of dietary fiber on insulin resistance [4,6,44], metabolic syndrome [5] and type 2 diabetes mellitus [34,45] has been well-documented. McKeown et al [46] observed that a higher dietary glycemic index was unfavorably associated with surrogate measures of insulin resistance. In contrast, no association was found between dietary glycemic index and measures of insulin resistance in either the Insulin Resistance Atherosclerosis Study [6] or Zutphen Elderly Study [47]. Inconsistencies between studies may in part be attributed to the different methods used to determine insulin sensitivity, the different populations studied, and methods of dietary assessment.

Some, but not all, observational studies have found a significant association between sugar-sweetened soft drinks and obesity [48-50]. Using cluster analysis, Wirfalt et al [28] observed that individuals in the Soft Drinks pattern had a significantly higher mean BMI compared to individuals in the Skim Milk and Meat-Cheese patterns. The “Soda” pattern had highest energy contribution from carbohydrate and highest glycemic index. Previous studies have demonstrated that high carbohydrate diets contribute to decreasing HDL cholesterol and increasing triacylglycerol concentrations [51,52]. Findings from several observational studies have consistently found that glycemic index is inversely related to HDL cholesterol concentration [53,54].

Using data from an earlier examination in the Framingham Offspring Cohort, Sonnenberg and colleagues observed that obese and non-obese women in the ‘empty calories’ cluster had a higher prevalence of the metabolic syndrome [14]. Despite differences in the type of FFQ administered and the defining of the clusters, this dietary pattern characterized by higher of sugar sweetened beverages and lower intakes of dietary fiber and vegetables, is similar to the “Soda” dietary pattern derived in this cluster analysis. Individuals in the “Soda” pattern displayed several metabolic syndrome abnormalities i.e higher waist circumference and triacylglycerol and lower HDL cholesterol. However, these differences were not statistically significant compared to the “Fruits, Reduced Fat Dairy and Whole Grains” pattern in part due to the small number of subjects in this pattern (n=210).

Two prospective studies have observed that diet soda consumption is positively associated with the metabolic syndrome [16,50]. It is possible that *diet* soda consumption may be associated with a particular dietary pattern, or alternatively a reflection of a dietary change due to some underlying metabolic disease. In the present study, only those individuals in the “Soda” cluster differed with respect to diet soda consumption i.e. they consumed significantly less diet soda compared to the other clusters. We previously found that diet soda consumption was not associated with any surrogate measures of insulin resistance after adjustment for potential confounders [43].

In this study, individuals in the “Beer” pattern had significant higher HDL cholesterol concentration compared to those in the “Fruits, Reduced Fat Dairy and Whole Grains” pattern. The inverse association between alcohol consumption and coronary heart disease has been observed in many observational studies around the world [55]. It is estimated that approximately 50% of the benefit of moderate alcohol consumption could be explained by the direct effect of alcohol on HDL cholesterol [56,57]. A meta-analysis of experimental studies found that a dose of 30 g of alcohol a day increased the concentration of HDL cholesterol by 3.99 mg/dl (95% CI, 3.25-4.73) [58]. Although higher beer intake was associated with a better HDL cholesterol level, individuals in the beer pattern had a poorer

overall diet, for instance, fewer fruits, vegetables, whole grains, and less reduced fat dairy. In addition, individuals in the “Beer” pattern had a significantly lower overall diet quality score compared with individuals in the “Fruits, Reduced Fat Dairy and Whole Grains” pattern.

Strength of this study includes its large sample size and inclusion of multiple insulin resistance phenotypes measured in a clinical setting. The main limitation is the cross-sectional study design. Since the diet and insulin resistance phenotypes data were collected at the same time, the causal relationship can not be assessed due to uncertainty regarding the timing of exposure and outcome, so further prospective studies are needed to examine the effect of diet on insulin resistance using dietary patterns to characterize exposures. Although we adjusted for physical activity, residual confounding caused by lifestyle behaviors and social economic status factors may arise in this study. The characterization of the food groups used in this study is limited by the dietary data obtained by self-reported FFQ. Although the FFQ has limitations in estimating absolute intake for individuals, it is a feasible and valid method to rank (or differentiate) people according to their usual diet. Differences in food and nutrient intake profile across clusters, as depicted in Table 2 and 3, demonstrate the utility of the cluster analysis for discriminating dietary exposure within the cohort. In addition, dietary patterns derived by cluster analysis using FFQ data have been validated against 3-day food records specifically in the Framingham Offspring Study [33,59]. Because the participants of Framingham Offspring Study are predominantly white Americans, the results from this study may not be readily generalized to other populations who have different dietary behaviors.

In conclusion, our findings suggest that consumption of a diet rich in fruits, vegetables, whole grains and reduced fat dairy protects against insulin resistance phenotypes; displacing these healthy choices with meat, refined grains, high fat dairy, sweet baked foods, candy and sugar sweetened soda promotes insulin resistant phenotypes.

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Table 1

Percentage energy contribution from selected food groups across the four dietary patterns among 2875 non-diabetic adults participating in the Framingham Offspring Study at the fifth examination cycle *

	Fruits Reduced Fat Dairy and Whole Grains (n=577)		Refined Grains and Sweets (n= 1846)		Beer (n=242)		Soda (n=210)	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
High fat dairy	5.1[a]	0.2	**6.8[b]**	0.1	6.4[b]	0.3	6.1[ab]	0.4
Reduced fat dairy	**5.1[a]**	0.2	3.8[b]	0.1	2.8[c]	0.3	2.2[c]	0.3
High fat dairy desserts	0.8[a]	0.1	**1.2[b]**	0.0	0.9[ab]	0.1	**1.2[b]**	0.1
Reduced fat dairy deserts	0.4	0.1	0.4	0.0	0.3	0.1	0.3	0.1
Margarine	1.2[ab]	0.1	1.4[a]	0.0	1.1[b]	0.1	**1.5[ab]**	0.1
Miscellaneous fats	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0
Fruit juices	**5.5[a]**	0.1	2.2[b]	0.1	1.9[b]	0.2	2.0[b]	0.2
Fruits	**8.5[a]**	0.2	5.0[b]	0.1	3.5[c]	0.3	3.2[c]	0.3
Fruit drinks	**2.8[a]**	0.1	1.6[bc]	0.1	1.2[b]	0.2	2.1[ac]	0.2
Tofu and beans	**0.9[a]**	0.0	0.6[b]	0.0	0.6[b]	0.1	0.5[b]	0.1
Nuts and seeds	1.8	0.1	1.9	0.1	1.8	0.2	1.6	0.2
Vegetables	**5.0[a]**	0.1	3.9[b]	0.0	3.6[bc]	0.1	3.2[c]	0.1
Starchy vegetables	4.9	0.1	4.9	0.1	4.8	0.2	4.6	0.2
Eggs	0.8	0.0	0.8	0.0	0.7	0.1	0.8	0.1
Poultry	**6.0[a]**	0.2	5.5[b]	0.1	4.6[c]	0.3	4.4[c]	0.3
Processed meat	1.2[a]	0.1	1.9[b]	0.0	**2.0[b]**	0.1	**2.0[b]**	0.1
Liver	0.05[a]	0.01	**0.09[b]**	0.01	0.07[ab]	0.02	0.07[ab]	0.02
Meat	4.8[a]	0.2	6.6[b]	0.1	6.4[b]	0.3	**6.9[b]**	0.3
Fish and other seafood	**3.3[a]**	0.1	2.4[b]	0.0	2.1[bc]	0.1	2.0[c]	0.1
Whole grain cereal	**2.2[a]**	0.1	1.6[b]	0.1	0.9[c]	0.2	0.8[c]	0.2
Refined grain cereal	**1.3[a]**	0.1	0.8[b]	0.0	0.5[b]	0.1	0.8[b]	0.1
Whole grains	**6.6[a]**	0.2	3.7[b]	0.1	2.8[c]	0.3	2.0[c]	0.3
Refined grains	7.3[a]	0.2	**9.5[b]**	0.1	7.0[a]	0.3	7.8[a]	0.3
Pasta	**3.2[a]**	0.1	3.0[a]	0.1	2.8[ab]	0.2	2.4[b]	0.2
Chocolate	1.0[a]	0.1	2.4[b]	0.1	2.0[b]	0.2	**2.7[b]**	0.2

	Fruits Reduced Fat Dairy and Whole Grains (n=577)		Refined Grains and Sweets (n= 1846)		Beer (n=242)		Soda (n=210)	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Candy w/out chocolate	0.5^{a}	0.1	$\mathbf{0.9^{b}}$	0.1	0.5^{ab}	0.2	0.8^{ab}	0.2
Sweet baked foods	2.9^{a}	0.2	$\mathbf{9.0^{b}}$	0.1	3.9^{a}	0.3	6.1^{c}	0.3
Miscellaneous sweets	1.4^{a}	0.1	1.5^{a}	0.0	1.2^{a}	0.1	$\mathbf{2.0^{b}}$	0.1
Vegetable oils	$\mathbf{2.7^{a}}$	0.1	2.6^{a}	0.1	2.6^{a}	0.2	2.0^{b}	0.2
Chowder/cream soup	0.4^{a}	0.0	0.5^{b}	0.0	0.4^{ab}	0.0	0.4^{ab}	0.0
Soda	1.1^{a}	0.1	1.5^{b}	0.1	1.7^{b}	0.2	$\mathbf{15.9^{c}}$	0.2
Beer	0.9^{a}	0.1	0.9^{a}	0.1	$\mathbf{18.1^{b}}$	0.2	1.1^{a}	0.2
Red wine	$\mathbf{0.8^{a}}$	0.1	0.5^{b}	0.0	$\mathbf{0.8^{ab}}$	0.1	0.3^{b}	0.1
White wine	$\mathbf{1.1^{a}}$	0.1	0.8^{b}	0.1	0.8^{ab}	0.1	0.3^{c}	0.1
Liquor	$\mathbf{2.1^{a}}$	0.1	1.2^{b}	0.1	1.5^{ab}	0.2	1.2^{b}	0.2
Coffee	0.6	0.02	0.7	0.01	0.6	0.04	0.6	0.04
Mixed dishes	3.9^{a}	0.2	$\mathbf{5.6^{b}}$	0.1	4.8^{c}	0.2	$\mathbf{5.6^{bc}}$	0.3
Salty snacks	$\mathbf{1.0^{a}}$	0.1	1.3^{b}	0.0	1.2^{ab}	0.1	$\mathbf{1.5^{c}}$	0.1
Fired food	0.5^{a}	0.0	0.6^{b}	0.0	0.6^{bc}	0.0	$\mathbf{0.7^{c}}$	0.0
Diet soda (servings/d)	$\mathbf{0.6^{a}}$	0.0	$\mathbf{0.6^{a}}$	0.0	0.5^{a}	0.1	0.2^{b}	0.1

*Adjusted for age and sex.

^{a,b,c,d}Values in the same row with different superscript letters are significantly different (P<0.05) using Tukey-Kramer's adjustment for multiple comparisons; Means that are underlined are lowest and means that are bold are highest in the row.

Table 2

Sample characteristic, nutrient intake, glycemic index and glycemic load across the four dietary patterns

	Fruits, Reduced Fat Dairy and Whole Grains (n=577)		Refined Grains and Sweets (n=1846)		Beer (n=242)		Soda (n=210)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sample characteristics								
Age at exam 5 (yrs)	55.7	0.4	53.8	0.2	51.5	0.6	51.5	0.7
Sex (%, male)	32.8		41.5		87.2		53.3	
Nutrients *								
Energy (KJ/d)	7236^{a}	106	7982^{b}	59	7955^{b}	165	**8296^{b}**	173
Protein (% energy)	**17.5^{a}**	0.1	17.1^{b}	0.1	15.0^{c}	0.2	14.4^{c}	0.2
Carbohydrate (% energy)	55.0^{a}	0.3	50.0^{b}	0.2	45.0^{c}	0.5	**56.2^{a}**	0.5
Sucrose (% energy)	9.1^{a}	0.2	10.2^{b}	0.1	7.1^{c}	0.3	**13.6^{d}**	0.3
Fiber (g/d)	**21.7^{a}**	0.2	17.3^{b}	0.1	15.6^{c}	0.4	12.7^{d}	0.4
Alcohol (% energy)	4.4^{a}	0.2	2.9^{b}	0.1	**14.4^{c}**	0.3	2.5^{b}	0.3
Total fat (% energy)	23.4^{a}	0.2	**29.5^{b}**	0.1	25.2^{c}	0.4	26.6^{d}	0.4
Saturate fat (% energy)	8.6^{a}	0.1	**11.3^{b}**	0.1	9.9^{c}	0.2	10.5^{c}	0.2
Monounsaturate fat (% energy)	9.2^{a}	0.1	**12.1^{b}**	0.1	10.2^{c}	0.2	10.9^{d}	0.2
Polyunsaturate fat (% energy)	5.6^{a}	0.1	**6.1^{b}**	0.0	5.1^{c}	0.1	5.2^{c}	0.1
Cholesterol (mg/d)	207^{a}	3	**237^{b}**	2	206^{a}	5	217^{a}	5
Potassium (mg/d)	**3333^{a}**	42	3032^{b}	23	2845^{c}	66	2581^{d}	69
Magnesium (mg/d)	**328^{a}**	5	298^{b}	3	325^{a}	7	248^{c}	7
Calcium (mg/d)	**858^{a}**	18	842^{a}	10	698^{b}	28	692^{b}	29
Sodium (mg/d)	1955^{a}	33	**2245^{b}**	18	1986^{a}	51	1996^{a}	53
Glycemic index	77.8^{a}	0.2	78.2^{a}	0.1	73.4^{b}	0.3	**81.3^{c}**	0.3
DGAI	**11.1^{a}**	0.1	8.6^{b}	0.1	8.0^{c}	0.1	7.7^{c}	0.2

DGAI: Dietary Guidelines Adherence Index, a measure of diet quality based on adherence to the key dietary intake recommendations in 2005 Dietary Guidelines for Americans.

^{a,b,c,d}Values in the same row with different superscript letters are significantly different (P<0.05) using Tukey-Kramer's adjustment for multiple comparisons; Means that are underlined are lowest and means that are bold are highest in the row.

*Adjusted for age, sex and total energy

Table 3

Insulin resistance phenotypes across the four dietary patterns

	Fruits, Reduced Fat Dairy and Whole Grains (n=577)		Refined Grains and Sweets (n=1846)		Beer (n=242)		Soda (n=210)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Waist circumference (cm) *	90.7[a]	0.5	92.4[b]	0.3	91.1[ab]	0.8	**92.5[ab]**	0.9
BMI (kg/m^2) *	26.6[a]	0.2	**27.3[b]**	0.1	26.5[ab]	0.3	**27.3[ab]**	0.3
Fasting insulin (μU/ml) †	28.0[a]	0.4	28.8[a]	0.2	27.8[a]	0.6	**31.3[b]**	0.7
2-h post-challenge insulin (μU/ml) †	87.3[ab]	2.7	92.8[ab]	1.5	82.4[a]	4.1	**100.4[b]**	4.3
Insulin sensitivity index (ISI $_{0,120}$) †	26.8	0.3	26.6	0.2	27.6	0.4	26.5	0.5
HDL cholesterol (mmol/l) †	1.31[a]	0.01	1.31[a]	0.01	**1.46[b]**	0.02	1.25[a]	0.02
Triacylglycerol (mmol/l) †	1.53	0.04	1.54	0.02	1.55	0.07	1.59	0.07
Systolic blood pressure (mm Hg) †,‡	123.7	0.7	121.8	0.4	124.1	1.1	123.3	1.1
Diastolic blood pressure (mm Hg) †,‡	74.6	0.4	73.8	0.2	73.3	0.7	74	0.7

a,b,c,d Values in the same row with different superscript letters are significantly different (P<0.05) using Tukey-Kramer's adjustment for multiple comparisons; Means that are underlined are lowest and means that are bold are highest in the row.

* Adjusted for age, sex, smoking, physical activity, treatment of hypertension, and total energy.

† Adjusted for age, sex, waist circumference, smoking, physical activity, treatment of hypertension, and total energy intake.

‡ Excluded those taking blood pressure medications.