The 2005 Dietary Guidelines for Americans and Insulin Resistance in the Framingham Offspring Cohort

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OBJECTIVE — The aim of this study was to examine the relationship between a diet consistent with the 2005 Dietary Guidelines for Americans (DGA), as assessed by the 2005 Dietary Guidelines for Americans Adherence Index (DGAI), and measures of insulin resistance in the Framingham Heart Study Offspring Cohort.

RESEARCH DESIGN AND METHODS — We examined cross-sectional associations between DGAI score and degree of insulin resistance as measured by the homeostasis model assessment of insulin resistance (HOMA-IR) and fasting insulin in 3,082 participants in the Framingham Offspring Cohort fifth examination (January 1991–June 1995).

RESULTS — Participants in the highest quintile category of the DGAI score had significantly lower HOMA-IR than those in the lowest quintile category after adjusting for age, sex, and waist circumference (6.4 compared with 6.7, $P = 0.04$). We observed a significant interaction between DGAI score and sex, and upon stratification, the association appeared to be largely confined to women (5.9 compared with 6.6, $P < 0.001$). No association was apparent in men (7.2 compared with 7.1, $P = 0.30$). Similar associations were evident between the DGAI score and fasting insulin.

CONCLUSIONS — Consumption of a diet consistent with the 2005 DGA may be an effective means to limit insulin resistance in women.

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The Dietary Guidelines for Americans (DGA), dietary recommendations intended to decrease chronic disease risks among American adults, were first released in 1980 by the U.S. Departments of Agriculture and Health and Human Services (1,2). A limited number of studies have examined whether adherence to earlier versions of the DGA was associated with lower risk of overall chronic disease, including cardiovascular disease, but findings were weak or inconclusive (3,4). Insulin resistance is an important risk factor for cardiovascular disease (CVD) (5–7) and type 2 diabetes (8,9). Fasting insulin, a marker of insulin resistance, was not related to the Healthy Eating Index (HEI), which measures adherence to an earlier version of the DGA, although fasting glucose and C-peptide levels were lower among those consuming healthier diets (10). Previous investigations have also considered associations between indexes of adherence to earlier versions of the DGA and markers of inflammation (11) and components of metabolic syndrome (10). The sixth edition, released in 2005, represents a significant departure from the guidelines written over the past 20 years by focusing on energy density and obesity prevention (12,13). No study to date has examined the relation between adherence to the 2005 DGA and CVD risk or intermediate markers of risk.

We developed the 2005 Dietary Guidelines for Americans Adherence Index (DGAI) to determine whether a diet consistent with the 2005 DGA was associated with a lower risk of chronic disease (12,14). This study assessed the relationship between adherence to the 2005 DGA and insulin resistance, as measured by HOMA-IR, and fasting insulin in the Framingham Offspring Cohort.

RESEARCH DESIGN AND METHODS

— The original Framingham Heart Study began in 1948 with 5,209 adults, aged 28–62 years, residing in Framingham, Massachusetts (15). The offspring of these participants and each offspring's spouse were invited to participate in the Framingham Heart Study Offspring Cohort, and 5,135 of the 6,838 eligible individuals participated in the first examination between 1971 and 1975 (16). A total of 3,799 participants were examined at the fifth examination of the Framingham Offspring Cohort (January 1991–June 1995). Usable food frequency questionnaire (FFQ) data were available for 3,418 (90%) of the participants at this examination. In addition, individuals were excluded if they were missing covariates essential to determine the DGAI score, including height, weight, age, and physical activity score ($n = 95$); if they had diagnosed diabetes based on use of

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Abbreviations: CRP, C-reactive protein; CVD, cardiovascular disease; DGA, Dietary Guidelines for Americans; DGAI, Dietary Guidelines for Americans Adherence Index; FFQ, food frequency questionnaire; HEI, Healthy Eating Index; HOMA-IR, homeostasis model assessment of insulin resistance; RFS, Recommended Food Score.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

insulin or oral hypoglycemic medication ($n = 110$); or if they were missing information concerning diabetes status ($n = 131$). The final sample included 3,082 participants.

Dietary data

Dietary intake was assessed using a semiquantitative FFQ, version 1988-GP, developed by Willett and colleagues (17,18). The questionnaires were mailed to the participants before the examination, and the participants were asked to bring the completed questionnaire with them to their appointment. The FFQ consisted of 126 items, including a list of foods with a standard serving size and a selection of nine frequency categories ranging from "never or <1 serving/month" to "≥6 servings/day." Participants were asked to report their frequency of consumption of each food item during the last year. There were also separate questions about vitamin and mineral supplements and type of breakfast cereal most commonly consumed and an area to write in foods commonly consumed that were not listed on the FFQ. Dietary information was judged as unreliable and excluded from further analysis if reported energy intakes were <2.51 MJ/day (600 kcal) for all or >16.74 MJ/day (4,000 kcal/day) for women and >17.57 (4,200 kcal/day) for men or if ≥12 food items were left blank. Participants who met the energy intake criteria and had <12 blank items were included in analyses and were considered to be nonconsumers of the missing items.

DGAI

The DGAI was developed to assess adherence to 16 of the 23 key recommendations in the 2005 DGA, including all of the recommendations that pertain specifically to dietary intake (12,14). Because the DGAI was developed to assess dietary recommendations for the general population, the recommendations for vulnerable populations (e.g., pregnant women) and for nondietary intake behaviors (e.g., oral hygiene, physical activity, and food safety) were excluded from the index. Specifics concerning the scoring of the DGAI are described elsewhere (14) and summarized briefly below.

There are a total of 20 items on the DGAI. Eleven index items assessed the "food intake" recommendations (assessed at 1 of the 10 calorie-specific adult food intake patterns from the U.S. Department of Agriculture food guide) (12). Each participant's calorie level was based on the "estimated energy requirement" equation, which included: height, weight, age, sex, and physical activity (19). Physical activity was determined using the "walking equivalents method" as described in the energy section of the DRI (19).

Nine items assessed the "healthy choice" (nutrient intake) recommendations, which are given in absolute amounts or as a percentage of total kilocalories of intake, and are the same for each calorie level and therefore for all individuals. Each item has a maximum value of 1.0, and most have an intermediate value of 0.5 (for partial adherence), while 0 points were awarded for nonadherence. To limit the likelihood that one could receive a higher score solely by consuming more food, a major shortcoming of previous indexes, a penalty for overconsuming energy-dense foods was included (20). The maximum possible DGAI score is 20 points.

Laboratory determinations

Fasting plasma glucose levels were measured in fresh plasma with a hexokinase reagent kit (A-Gene Glucose Test; Abbott, South Pasadena, CA), and glucose assays were run in duplicate. The intra-assay coefficient of variation (CV) for this method at the fifth examination cycle was <3% (21). Fasting insulin was measured in EDTA plasma as total immunoreactive insulin (Coat-A-Count Insulin; Diagnostic Products, Los Angeles, CA) and run in duplicate. The intra- and interassay CVs ranged from 5 to 10%, and the lower limit of sensitivity was 8 pmol/l (21).

Determination of insulin resistance

HOMA-IR was used to assess the degree of insulin resistance, as follows:

$$\frac{\text{Fasting plasma insulin } (\mu\text{U/ml}) \times \text{fasting plasma glucose (mmol/l)}}{22.5}$$

This method has been shown in studies to correlate well with results obtained using euglycemic clamps ($R = 0.88$, $P < 0.001$) (22). In addition, fasting insulin concentrations were used to estimate the degree of insulin resistance.

Lifestyle variables

Height (to the nearest 0.25 inch) and weight (to the nearest 0.25 lb) were measured with the participants standing, with shoes off, wearing only a hospital gown. BMI was calculated as weight in kilograms divided by the square of height in meters. Waist circumference was measured at the umbilicus while the participant was standing, with the tape measure parallel to the floor. The use of any medications, including hypoglycemic medication (insulin or oral agents) was determined during the physical exam. Information on age (years), current smoking (yes/no), current multivitamin use (yes/no), and physical activity (assessed as a weighted average of the proportion of a typical day spent sleeping and performing sedentary, slight, moderate, or heavy physical activities, expressed in metabolic equivalents) were also assessed at the same time (16,23).

Statistical methods

All statistical analyses were conducted using SAS statistical software version 9.1 (SAS Institute, Cary, NC). HOMA-IR and fasting insulin were positively skewed, and a natural logarithm transformation was applied to normalize these data. Geometric means were calculated for fasting insulin and HOMA-IR. Unless otherwise noted, statistical significance indicated a P value <0.05.

Participant characteristics were compared across quintile categories of DGAI score, adjusted for sex and age, using the SAS procedure PROC GLM. P values for linear trend between the DGAI score as a continuous variable and participant characteristics were assessed using linear regression for continuous characteristics and logistic regression for dichotomous characteristics.

Geometric mean HOMA-IR and insulin concentrations were compared across quintile categories of DGAI score using the SAS procedure PROC GLM. Potential confounding variables considered in analyses included age, sex, waist circumference, BMI, smoking, total reported energy intake, multivitamin use, and physical activity. To assess linear trend, we first examined the linearity of the relationship between the DGAI score and HOMA-IR and fasting insulin levels using the SAS LOESS procedure. P value for linear trend then was determined as the P value for the DGAI linear regression coefficient relating the DGAI score as a continuous variable to HOMA-IR and insulin levels using SAS PROC REG. First-order interactions were tested in separate models between DGAI score and those factors that were independent predictors of either HOMA-IR or fasting insulin levels.

Table 1—*Participant characteristics* according to quintile category of the 2005 DGAI*

	2005 DGAI quintile category					
	1 (range 2.50–6.75)	2 (range 7.00–8.50)	3 (range 8.75–10.25)	4 (range 10.50–12.00)	5 (range 12.25–17.00)	*P* for trend†
n (*N* = 3,082)	586	625	646	592	633	
DGAI score‡	5.50	8.00	9.50	11.25	13.25	
Nutrient subscore§	3.00	4.50	5.25	5.75	6.75	
Food group subscore‖	2.50	3.00	4.50	5.50	7.00	
Female (%)	26.7	40.3	53.1	67.9	77.4	<0.001
Age (years)	51.1	53.9	54.3	55.9	57.0	<0.001
Waist circumference (cm)	95	94	92	91	89	<0.001
BMI (kg/m^2)	28.0	27.8	27.2	27.0	26.3	<0.001
Fasting plasma glucose (mg/dl)	97.4	98.3	98.5	99.0	96.1	0.36
Total reported calories (kcal/day)	1838	1828	1865	1909	1893	0.07
Physical activity score (MET)	35.3	34.8	34.0	35.0	34.6	0.05
Current smokers (%)	35.0	24.3	18.8	10.8	7.7	<0.001
Multivitamin users (%)	23.4	24.5	26.8	31.5	40.1	<0.001

Data are median and percentage unless otherwise indicated. *Means and percentages adjusted for sex and age. Age is adjusted for sex only and sex for age only. †*P* value by linear regression for continuous variable or logistic regression for dichotomous variables. ‡Scores range from 0–20 possible points. §Scores range from 0–11 possible points and are assessed at the same level for all participants. ‖Scores range from 0–9 possible points and are assessed on a calorie-specific level. MET, metabolic equivalent.

RESULTS — The final sample included 3,082 participants with a mean age of 54 ± 9.8 years (mean ± SD) (range 26–82) and a mean BMI of 27.3 ± 4.8 kg/m^2, of which 1,438 were men, mean age 54.7 ± 9.9 years, mean BMI 28.2 ± 4.1 kg/m^2, and 1,644 were women, mean age 54.2 ± 9.7 years, mean BMI 26.5 ± 5.3 kg/m^2. Age, sex, and BMI were not significantly different between those included in the final sample and those excluded.

The DGAI score ranged from 2.5 to 17.0 and was associated with several participant characteristics (Table 1). Participants in the highest DGAI quintile category were more likely to be women than men (77 vs. 27%, *P* for trend <0.001), were older (57 vs. 51 years, *P* for trend <0.001), and were more likely to use multivitamin supplements (40 vs. 23%, *P* for trend <0.001). They also had lower waist circumference (89 vs. 95 cm, *P* trend <0.001) and BMI (26.3 vs. 28.0, *P* for trend <0.001) and were less likely to be current smokers (8 vs. 35%, *P* for trend <0.001). There was a weak, inconsistent, inverse trend across DGAI categories for physical activity (*P* for trend 0.05), and no significant trends were observed between the DGAI score and total reported energy intake and fasting plasma glucose concentrations.

A higher DGAI score was inversely associated with HOMA-IR after adjustment for age and sex (Table 2). This association was attenuated but remained statistically significant after waist circumference was added to the model (*P* for trend 0.04). Additional adjustment for BMI, smoking, multivitamin supplement use, physical activity, and energy intake did not significantly affect this association (data not shown).

First-order interactions between DGAI score and age, sex, and waist circumference were tested in separate models, and a significant interaction was observed only for sex ($P < 0.001$). Therefore, the analyses of DGAI score, HOMA-IR, and fasting insulin were stratified by sex (Table 2). When DGAI was controlled for age alone, there was a significant relationship seen in both men (*P* for trend <0.01) and women (*P* for trend <0.001). After adjustment for age and waist circumference, the relationship was no longer significant in men (*P* for trend 0.30), but it remained highly significant in women (*P* for trend <0.001). Further adjustment for BMI, smoking, multivitamin supplement use, physical activity, and energy intake had little effect on the association in either men or women (data not shown).

The results for fasting insulin were very similar to those for HOMA-IR (Table 2), as expected in this nondiabetic sample in which elevated fasting glucose concentrations would not be common. The Spearman rank correlation coefficient between HOMA-IR score and fasting insulin was 0.94.

The index items were assessed individually to determine whether there was one item or group of items that was largely responsible for the relationship between the total index score and HOMA-IR. Most individual index items, when controlled for age, sex, BMI, and waist circumference were not significantly associated with HOMA; however, a higher score on a few index items proved to be related to lower HOMA-IR. Those fully meeting the intakes for fiber, whole grains, dark green vegetables, trans fat, and alcohol recommendations had significantly lower HOMA-IR than those who received a zero score for these items ($P < 0.05$).

CONCLUSIONS — This is the first examination of the relationship between a diet consistent with the 2005 DGA and insulin resistance. Our findings suggest that, in the Framingham Offspring Cohort, women who consumed a diet more consistent with the 2005 DGA had better insulin sensitivity than those who did not, whereas the 2005 DGA score was not associated with insulin sensitivity among men.

The reason for the observed difference between sexes is not apparent. The

Table 2—*Geometric mean HOMA-IR and fasting insulin across quintile category of DGAI*

	2005 DGAI quintile category					
	1 (range 2.50–6.75)	2 (range 7.00–8.50)	3 (range 8.75–10.25)	4 (range 10.50–12.00)	5 (range 12.25–17.00)	*P* for trend*
All participants (n = 3,082)	586	625	646	592	633	
HOMA-IR						
Model 1†	7.0 (6.8–7.2)‡	6.9 (6.7–7.1)	6.8 (6.6–7.0)	6.5 (6.3–6.7)	6.1 (5.9−6.3)	<0.001
Model 2§	6.7 (6.5–6.9)	6.7 (6.6–6.9)	6.8 (6.6–7.0)	6.6 (6.4–6.8)	6.4 (6.3–6.6)	0.04
Fasting insulin						
Model 1	29.6 (28.9–30.5)	29.2 (28.4–29.9)	28.7 (28.0–29.5)	27.4 (26.7−28.1)	26.4 (25.8–27.1)	<0.001
Model 2	28.7 (28.0–29.4)	28.6 (27.9–29.2)	28.7 (28.1–29.4)	27.7 (27.1–28.4)	27.5 (26.8–28.1)	0.004
Women (n = 1,644)	164	253	344	399	484	
HOMA-IR						
Model 1	6.7 (6.3–7.1)	6.6 (6.3–6.9)	6.3 (6.1–6.6)	6.1 (5.9–6.3)	5.8 (5.6–6.0)	<0.001
Model 2	6.6 (6.3–6.9)	6.3 (6.1–6.6)	6.2 (6.0–6.4)	6.1 (5.9–6.3)	5.9 (5.7–6.1)	<0.001
Fasting insulin						
Model 1	29.8 (28.5–31.1)	27.3 (26.4–28.4)	27.3 (26.4–28.1)	26.8 (26.0–27.6)	25.5 (24.7–26.2)	<0.001
Model 2	28.1 (27.0–29.3)	27.6 (26.7–28.5)	27.5 (26.7–28.2)	26.5 (25.8–27.1)	26.3 (25.6–26.9)	<0.001
Men (n = 1,438)	422	372	302	193	149	
HOMA-IR						
Model 1	7.4 (7.1–7.7)	7.3 (7.0–7.7)	7.4 (7.1–7.8)	7.1 (6.7–7.4)	6.6 (6.2–7.1)	0.005
Model 2	7.1 (6.9–7.4)	7.2 (6.9–7.5)	7.6 (7.3–7.9)	7.3 (6.9–7.6)	7.2 (6.8–7.6)	0.30
Fasting insulin						
Model 1	30.6 (29.7–31.6)	29.7 (28.6–30.8)	30.9 (29.7–32.1)	28.6 (27.3–30.0)	27.7 (26.3–29.1)	0.002
Model 2	29.7 (28.9–30.6)	29.9 (29.0–30.8)	30.2 (29.3–31.3)	29.6 (28.4–30.8)	29.1 (27.8–30.6)	0.66

Data are means (95% CI) unless otherwise indicated. **P* value based on linear regression coefficient for DGAI linear as a continuous variable. †Model 1 adjusted for sex and age (sex strata controlled for age only). ‡Geometric means (95% CI). §Model 2 adjusted for variables in model 1 and waist circumference (sex strata controlled for age and waist circumference).

relationship between DGAI and both HOMA-IR (*P* for trend <0.01) and fasting insulin (*P* for trend 0.002) was attenuated by adjustment for waist circumference in men but not in women. Previous studies have found that waist circumference is a strong predictor of insulin resistance in both men and women (24–26). This has also been shown previously in this study population (6). It is unclear whether the relationship between DGAI score and HOMA-IR in men was confounded by waist circumference or whether waist circumference may be part of the causal pathway relating dietary intake and insulin resistance. It may also be possible that the difference between the association in men and women might be a result of the differential diet patterns in men and women achieving higher scores. We observed (data not shown) that among individuals in the highest DGAI quintile category, women had a significantly higher mean DGAI score than men ($P <$ 0.001). Moreover, women in the highest DGAI quintile category were more likely to achieve a higher DGAI score by meeting the recommendations for orange and starchy vegetables, grains, variety, total fat, and sodium, whereas men in the highest DGAI quintile were more likely to achieve a higher score by meeting the fiber and trans fat recommendations. There were also many differences in the diet patterns of men and women in the lowest quintile category. Such differences might be responsible, in part, for the observed differences between the DGAI score and insulin resistance in men and women.

When we assessed the index items to determine whether there was one item or group of items that was largely responsible for the relationship between the total index score and HOMA-IR, we observed that those fully meeting the intakes for fiber, whole grains, dark green vegetables, trans fat, and alcohol recommendations had significantly lower HOMA than those who received a zero score for these items. However, an overall healthy diet pattern as indicated by a higher total index score was more strongly associated with insulin resistance than any of the individual components. Moreover, the association between the overall score and insulin resistance does not appear to be a consequence of meeting any single index recommendation, but rather a consequence of meeting many different recommendations.

The few published studies assessing the relations between adherence to previous versions of the DGA and disease risk have been largely inconclusive. The HEI (20) has been used to assess overall disease outcomes in only two published studies (3,4). Both failed to show a relationship between a diet consistent with the DGA and decreased risk of overall chronic disease (CVD, cancer, and other nontraumatic death) but showed an inverse association with CVD risk in men only (4). A subsequent study suggested that the alternate HEI, which was a substantial modification of the previous HEI, improved prediction of overall chronic disease risk and CVD risk in both men and women (27).

In 2001, Harnack et al. (28), using an index based on the 2000 DGA that included items on both weight and physical activity, showed a statistically significant (15%) lower incidence of all cancers in women with the highest index scores. When the physical activity and body weight recommendations were removed from the index, it was no longer signifi-

cantly associated with a decrease in overall cancer risk. Rather than including weight and physical activity in our index, we chose to focus on the DGA dietary recommendations and to control for central adiposity, overweight, and physical activity.

The Recommended Food Score (RFS), which has been proposed as another means of assessing a diet consistent with the DGA, approximates healthy eating patterns based on variety in the diet. It measures the number of different foods consumed over a 1-week period that are consistent with the recommendations made in the 1990 DGA and is heavily weighted by fruit and vegetable consumption. It does not consider any macro- or micronutrient recommendations (29). Like the HEI, this index also has the inherent problem of being positively correlated with the number of foods consumed and therefore total calorie intake. It is, however, essential to consume a variety of foods to receive a high score, which makes the RFS an excellent measure of variety.

Several studies have examined the relationship between these diet scores and biomarkers for chronic disease risk. The RFS was shown to be related to overall mortality in women (30) but was not significantly associated with C-reactive protein (CRP) (31). Two studies have used this index to assess men and women together in relation to intermediate markers of disease, both using the National Health and Nutrition Examination Survey (NHANES) III population. Kant and Graubard (10) observed an inverse association between both the HEI (*P* for trend <0.05) and RFS (<0.05) scores and CRP levels. While Ford et al. (11), using the same population, found that the relationship with CRP was confined to women. Kant and Graubard also found that there was no relationship between RFS or HEI and fasting insulin or triglycerides, while there was a significant relationship for both with fasting glucose. The relationship between other intermediate markers of CVD risk, including homocysteine, CRP, and fibrinogen, were more strongly inversely related to RFS than HEI (10).

Our findings have some potential limitations. The DGAI was designed specifically for use with the Harvard semiquantitative FFQ (17,18). The semiquantitative nature of this dietary assessment questionnaire limits our ability to accurately measure energy intake. Another potential limitation was the cross-sectional and historical nature of these analyses, which does not allow us to directly determine whether a poor dietary pattern precedes the occurrence of reduced insulin sensitivity. Finally, our findings could be a consequence of confounding by determinants of insulin resistance or other healthy behaviors that we have not considered. However, the fact that the association between the DGAI score and levels of insulin resistance were maintained after adjustment for important known and suspected determinants of insulin resistance, such as age, abdominal adiposity (as waist circumference), and overweight (as BMI), and correlates of a healthy lifestyle, such as physical activity, smoking, and vitamin supplement use, argues against confounding as the basis for the observed association.

In the Framingham Offspring Cohort, we observed that a higher DGAI quintile score was associated with a lower HOMA-IR in women, suggesting that adherence to the 2005 DGA recommendations may favorably affect insulin resistance, an important intermediate marker of CVD and type 2 diabetes risk. More definitive studies are required to document the benefit of following a diet consistent with the 2005 DGA. Further work should concentrate on prospective assessment of adherence to the 2005 DGA and intermediate markers of risk for CVD and diabetes, such as insulin resistance, inflammatory markers, and metabolic syndrome.

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References

1. Davis C, Saltos E: Dietary recommendations and how they have changed over time. In *America's Eating Habits: Changes and Consequences*. Frazao E, Ed. Washington, DC, U.S. Department of Agriculture, Economic Research Service, 1999
2. *Nutrition and Your Health: Dietary Guidelines for Americans*. Home and Garden Bulletin no. 228. Washington, DC, U.S. Department of Agriculture and Department of Health and Human Services, 1980
3. McCullough ML, Feskanich D, Stampfer MJ, Rosner BA, Hu FB, Hunter DJ, Variyam JN, Colditz GA, Willett WC: Adherence to the Dietary Guidelines for Americans and risk of major chronic disease in women. *Am J Clin Nutr* 72:1214–1222, 2000
4. McCullough ML, Feskanich D, Rimm EB, Giovannucci EL, Ascherio A, Variyam JN, Spiegelman D, Stampfer MJ, Willett WC: Adherence to the Dietary Guidelines for Americans and risk of major chronic disease in men. *Am J Clin Nutr* 72:1223–1231, 2000
5. Smiley T, Oh P, Shane LG: The relationship of insulin resistance measured by reliable indexes to coronary artery disease risk factors and outcomes: a systematic review. *Can J Cardiol* 17:797–805, 2001
6. Rutter MK, Meigs JB, Sullivan LM, D'Agostino RB Sr, Wilson PW: Insulin resistance, the metabolic syndrome, and incident cardiovascular events in the Framingham Offspring Study. *Diabetes* 54:3252–3257, 2005
7. Hanley AJ, Williams K, Stern MP, Haffner SM: Homeostasis model assessment of insulin resistance in relation to the incidence of cardiovascular disease: the San Antonio Heart Study. *Diabetes Care* 25: 1177–1184, 2002
8. Martin BC, Warram JH, Krolewski AS, Bergman RN, Soeldner JS, Kahn CR: Role of glucose and insulin resistance in development of type 2 diabetes mellitus: results of a 25-year follow-up study. *Lancet* 340: 925–929, 1992
9. Warram JH, Martin BC, Krolewski AS, Soeldner JS, Kahn CR: Slow glucose removal rate and hyperinsulinemia precede the development of type II diabetes in the offspring of diabetic parents. *Ann Intern Med* 113:909–915, 1990
10. Kant AK, Graubard BI: A comparison of three dietary pattern indexes for predicting biomarkers of diet and disease. *J Am Coll Nutr* 24:294–303, 2005
11. Ford ES, Mokdad AH, Liu S: Healthy Eating Index and C-reactive protein concentration: findings from the National Health and Nutrition Examination Survey III, 1988–1994. *Eur J Clin Nutr* 59:278–283, 2005
12. *Dietary Guidelines for Americans, 2005*. 6th ed. Washington, DC, U.S. Department of Agriculture and Department of Health and Human Services, 2005
13. *MyPyramid* [Web site]. Washington, DC, U.S. Department of Agriculture, 2005. Available from http://www.mypyramid.gov. Accessed 10 February 2006
14. Fogli-Cawley JJ, Dwyer JT, Saltzman E,

McCullough ML, Troy LM, Jacques PF: The 2005 Dietary Guidelines for Americans Adherence Index: development and application. *J Nutr* 136:2908–2915, 2006
15. Dawber TR, Kannel WB: An epidemiologic study of heart disease: the Framingham study. *Nutr Rev* 16:1–4, 1958
16. Feinleib M, Kannel WB, Garrison RJ, McNamara PM, Castelli WP: The Framingham Offspring Study: design and preliminary data. *Prev Med* 4:518–525, 1975
17. Willett WC, Sampson L, Stampfer MJ, Rosner B, Bain C, Witschi J, Hennekens CH, Speizer FE: Reproducibility and validity of a semiquantitative food frequency questionnaire. *Am J Epidemiol* 122:51–65, 1985
18. Rimm EB, Giovannucci EL, Stampfer MJ, Colditz GA, Litin LB, Willett WC: Reproducibility and validity of an expanded self-administered semiquantitative food frequency questionnaire among male health professionals. *Am J Epidemiol* 135: 1114–1126 [discussion 1127–1136], 1992
19. Panel on Macronutrients, Food and Nutrition Board, Institute of Medicine: *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein and Amino Acids* (*Macronutrients*). Washington, DC, National Academies Press, 2005
20. Kennedy ET, Ohls J, Carlson S, Fleming K: The Healthy Eating Index: design and applications. *J Am Diet Assoc* 95:1103–1108, 1995
21. Meigs JB, Nathan DM, Wilson PW, Cupples LA, Singer DE: Metabolic risk factors worsen continuously across the spectrum of nondiabetic glucose tolerance: the Framingham Offspring Study. *Ann Intern Med* 128:524–533, 1998
22. Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, Turner RC: Homeostasis model assessment: insulin resistance and beta-cell function from fasting plasma glucose and insulin concentrations in man. *Diabetologia* 28:412–419, 1985
23. Kannel WB, Sorlie P: Some health benefits of physical activity: the Framingham Study. *Arch Intern Med* 139:857–861, 1979
24. Onat A, Hergenc G, Turkmen S, Yazici M, Sari I, Can G: Discordance between insulin resistance and metabolic syndrome: features and associated cardiovascular risk in adults with normal glucose regulation. *Metabolism* 55:445–452, 2006
25. Racette SB, Evans EM, Weiss EP, Hagberg JM, Holloszy JO: Abdominal adiposity is a stronger predictor of insulin resistance than fitness among 50–95 year olds. *Diabetes Care* 29:673–678, 2006
26. Sierra-Johnson J, Johnson BD, Allison TG, Bailey KR, Schwartz GL, Turner ST: Correspondence between the Adult Treatment Panel III criteria for metabolic syndrome and insulin resistance. *Diabetes Care* 29:668–672, 2006
27. McCullough ML, Feskanich D, Stampfer MJ, Giovannucci EL, Rimm EB, Hu FB, Spiegelman D, Hunter DJ, Colditz GA, Willett WC: Diet quality and major chronic disease risk in men and women: moving toward improved dietary guidance. *Am J Clin Nutr* 76:1261–1271, 2002
28. Harnack L, Nicodemus K, Jacobs DR Jr, Folsom AR: An evaluation of the Dietary Guidelines for Americans in relation to cancer occurrence. *Am J Clin Nutr* 76: 889–896, 2002
29. Kant AK, Schatzkin A, Block G, Ziegler RG, Nestle M: Food group intake patterns and associated nutrient profiles of the US population. *J Am Diet Assoc* 91:1532–1537, 1991
30. Kant AK, Schatzkin A, Graubard BI, Schairer C: A prospective study of diet quality and mortality in women. *JAMA* 283:2109–2115, 2000
31. Fung TT, McCullough ML, Newby PK, Manson JE, Meigs JB, Rifai N, Willett WC, Hu FB: Diet-quality scores and plasma concentrations of markers of inflammation and endothelial dysfunction. *Am J Clin Nutr* 82:163–173, 2005