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Fruit and Vegetable Consumption and Diabetes Mellitus Incidence among U.S. Adults

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Background. Adequate fruit and vegetable intake may lower the risk of several chronic diseases, but little is known about how it affects the risk of diabetes mellitus.

Methods. We examined whether fruit and vegetable consumption was associated with diabetes incidence in a cohort of U. S. adults aged 25–74 years who were followed for about 20 years.

Results. In the analytic sample of 9,665 participants, 1,018 developed diabetes mellitus. The mean daily intake of fruits and vegetables as well as the percentage of participants consuming five or more fruits and vegetables per day was lower among persons who developed diabetes than among persons who remained free of this disease ($P < 0.001$). After adjustments for age, race or ethnicity, cigarette smoking, systolic blood pressure, use of antihypertensive medication, serum cholesterol concentration, body mass index, recreational exercise, nonrecreational exercise, and alcohol consumption, the hazard ratio for participants consuming five or more servings of fruits and vegetables per day compared with those consuming none was 0.73 (95% confidence interval (CI), 0.54–0.98) for all participants, 0.54 (95% CI, 0.36–0.81) for women, and 1.09 (95% CI, 0.63–1.87) for men. Adding education to the model changed the hazard ratios to 0.79 (95% CI, 0.59–1.06) for all participants, 0.61 (95% CI, 0.42–0.88) for women, and 1.14 (95% CI, 0.67–1.93) for men.

Conclusions. Fruit and vegetable intake may be inversely associated with diabetes incidence particularly among women. Education may explain partly this association.

Key Words: cohort studies; diabetes; diet; fruit; incidence; vegetables.

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INTRODUCTION

Diabetes mellitus is the seventh leading cause of mortality in the United States. Currently, about 16 million persons have diabetes mellitus in the United States [*1*]. Several studies have shown that the incidence and prevalence of diabetes mellitus are increasing [*2,3*]. The increases in recent years are most likely due to important body weight changes in the U.S. population [*4,5,6*]. The economic toll of this disease was estimated at about $98 billion in 1997 [*7*].

Obesity is clearly the dominant modifiable risk factor for diabetes mellitus. Nevertheless, other approaches to diabetes prevention need to be explored. Although the role of nutrition in the etiology of diabetes mellitus has long been examined [*8*], no particular nutrient, food, or dietary pattern—aside from hypercaloric consumption— has been consistently identified as increasing or decreasing the risk for diabetes mellitus.

Adequate intake of fruits and vegetables appears to lower the risks of all-cause mortality and morbidity and mortality from cardiovascular disease and cancer [*9,10*]. A few studies have also suggested that adequate fruit and vegetable consumption may lower the risk of developing diabetes [*11–13*]. To further explore this possibility, we examined the association between fruit and vegetable intake and diabetes incidence in a national sample of U.S. adults.

SUBJECTS AND METHODS

Adults aged 25–74 years who participated in the first National Health and Nutrition Examination Survey (NHANES I), conducted from 1971 to 1975, were followed through 1992–1993 ($n = 14{,}407$). The original sample was selected by using a complex sampling design so that results would be representative of the noninstitutionalized civilian population. Details of the NHANES I and the NHANES I Epidemiologic Follow-up Study (NHEFS) have been published elsewhere [*14–17*].

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Four attempts were made to contact participants or their surrogates in person and, during later follow-ups, by telephone as well: 1982–1984, 1986 (only participants aged ≥55 years), 1987, and 1992–1993. Permission was requested to obtain hospital records. Deaths were identified through searches of the National Death Index, the Health Care Financing Administration enrollee files, and other tracing mechanisms. A participant was considered deceased only if a death certificate had been received or a proxy interview had been completed to verify the death. Death certificates have been obtained for 97% of deceased participants through 1993.

A participant had incident diabetes if: (a) he or she confirmed that he or she had ever been told by a doctor that he or she had diabetes during any of the four follow-up contacts, (b) a hospitalization record listed the International Classification of Diseases-9-Clinical modification (ICD-9-CM) code 250 on any one of 10 diagnoses on the hospital discharge sheet, or (c) the death certificate included the ICD-9 code 250. Participants who reported that they had diabetes were asked the year of disease onset. We designated the midpoint of that year as the date of onset. For participants who did not report a year of onset, we assigned the midpoint between the last date of known contact and the date of the most recent interview. The date of onset was chosen as the date the condition was first reported or recorded on institutional records or death certificates.

Participants who reported at baseline that they had diabetes were considered prevalent cases as were participants who during later follow-up contacts reported a date of onset that occurred in the year of their baseline interview or earlier, and they were excluded from the analyses.

During the baseline examination, trained nutritionists interviewed 11,348 participants to collect dietary intake data with a single 24-hour recall, which asked about all foods consumed from midnight to midnight on the preceding day (14). Foods reported in the 24-hour recall were later coded by the interviewers, who used nutrient information from the *U.S. Department of Agriculture Handbook No. 8* and other sources [*18,19*].

We included the following as covariates in our analyses: age, race or ethnicity (African Americans, white), education (years), cigarette smoking (never, former, or current), systolic blood pressure (mm Hg), use of antihypertensive medication (yes/no), serum cholesterol concentration (mg/dL), body mass index (kg/m^2), recreational exercise (much, moderate, or little or no exercise), nonrecreational exercise (very active, moderately active, or quite inactive), and alcohol consumption (0, 1–2, or ≥3 drinks/day). The variable for cigarette smoking was constructed from responses asked during both the baseline interview and the first follow-up interview [*20,21*]. Two questions were used to create the categories of smoking: "Have you smoked at least 100 cigarettes during your entire life?" and "Do you smoke cigarettes now?" In addition, for some analyses we included data on total energy and fat intake, collected from a single 24-hour dietary recall.

Two-sample comparisons of categorical variables were done by using chi-square tests and of continuous variables by using *t*-tests. Using direct standardization, we standardized baseline characteristics and incidence rates to the age distribution from the 1980 census. Person-years were calculated for each participant from the time of entry into the study until one of the following conditions occurred: (a) the participant developed diabetes; (b) the participant died or left the study; or (c) follow-up was completed in 1993. The independent association between fruit and vegetable intake and diabetes incidence was examined using proportional hazard models. To account for the complex sampling design, the software SUDAAN was used in all analyses except for evaluation of proportionality assumptions, which were done in SAS [*22,23*].

Of the 14,407 participants of the NHEFS, 11,348 were administered the dietary questionnaires. After we deleted persons who were lost to follow-up, 10,925 participants remained. We excluded participants who were not white or African American, persons with insufficient information to establish diabetes incidence, persons with prevalent diabetes, pregnant women, and persons with missing data for covariates. These exclusions reduced the analytic sample to 9,665 participants, of whom 1,018 had incident diabetes.

RESULTS

The mean, median, and geometric mean intakes of fruits and vegetables per day were 3.4 (standard error (SE), 0.1), 3.0, and 3.1 servings per day (SE < 0.1). The range was 0–16 servings per day. For men, these values were 3.3 (SE, 0.1), 3.0, and 3.0 (SE, 0.1) servings per day, respectively, and the range was 0–16 servings per day. For women, these values were 3.5 (SE, 0.1), 3.0, and 3.2 (SE, 0.1) servings per day, respectively, and the range was 0–15 servings per day.

Participants who developed diabetes were older than participants who remained free of this disease (Table 1). After adjusting for age, participants with incident diabetes were less likely to be white, were less educated, had higher systolic blood pressures and cholesterol concentrations, were heavier, and were more likely to be sedentary than were participants who remained free of this disease. Furthermore, the mean intake of fruits and vegetables as well as the percentage of participants who consumed five or more fruits and vegetables per day were lower among persons who developed diabetes than among persons who remained free of this disease. Among men, the age-adjusted means for fruit and vegetable intake were 3.1 (SE, 0.2) servings per day for

TABLE 1

Age-Adjusted Means or Percentages (Standard Error) of Selected Characteristics at Baseline Examination among Adults Aged 25–74 Years, by Diabetes Status, NHEFS 1971–1976 to 1992–1993

	Participants with incident diabetes mellitus (n = 1,018)	Participants without incident diabetes mellitus (n = 8,647)	P value
Age (years)	50.7 (0.5)	6.4 (0.3)	<0.001
Men (%)	45.5 (2.4)	46.2 (0.6)	0.786
White (%)	81.5 (2.4)	90.3 (0.9)	<0.001
Education (years)	10.7 (0.2)	11.6 (0.1)	<0.001
Current smoker (%)	38.7 (2.7)	40.9 (0.8)	0.428
Systolic blood pressure (mm Hg)	139.4 (1.1)	130.5 (0.5)	<0.001
Cholesterol concentration (mg/dl)	223.2 (2.2)	218.1 (0.9)	0.023
Body mass index (kg/m²)	29.8 (0.3)	25.1 (0.1)	<0.001
Alcohol intake (drinks per day)	0.6 (0.1)	0.6 (<0.1)	0.336
Recreational exercise, % little or no exercise	51.7 (2.5)	42.5 (1.2)	<0.001
Nonrecreational activity, % quite inactive	10.9 (1.3)	9.3 (0.6)	0.196
Fruit and vegetable intake (servings per day)	3.0 (0.1)	3.4 (0.1)	<0.001
Consumption of ≥5 servings of fruits and vegetables per day (%)	19.3 (1.6)	28.0 (1.1)	< 0.001

diabetic men and 3.3 (SE, 0.1) servings per day for nondiabetic men (P = 0.257). The percentage consuming five or more servings of fruits and vegetables per day was 19.6% (SE, 2.7) among diabetic men and 25.6% (SE, 1.4) among nondiabetic men (P = 0.055). Among women, the age-adjusted means for fruit and vegetable intake were 2.9 (SE, 0.1) servings per day for diabetic women and 3.6 (SE, 0.1) servings per day for nondiabetic women (P = <0.001). The percentage consuming five or more servings of fruits and vegetables per day was 18.9% (SE, 2.0) among diabetic women and 30.2 (SE, 1.2) among nondiabetic women (P < 0.001).

The overall incidence rate decreased with increasing consumption of fruits and vegetables (Table 2). The proportional hazards model generally supported this pattern. After adjusting for age, race or ethnicity, cigarette smoking, systolic blood pressure, use of antihypertensive medication, serum cholesterol concentration, body mass index, recreational exercise, nonrecreational exercise, and alcohol consumption, the hazard ratio for participants consuming five or more servings of fruits and vegetables per day was 0.73 (95% CI, 0.54–0.98). When we also adjusted for education, the hazard ratio changed to 0.79 (95% CI, 0.59–1.06). Adding vitamin and mineral use, percentage calories from fat, and total energy intake to the model did not change the hazard ratio for participants consuming five or more servings of fruits and vegetables per day but did widen the confidence intervals. The hazard ratios for fruit and vegetable intake as a continuous variable were 0.97 (95% CI, 0.94–1.01) for all participants (P = 0.109), 1.01 (95% CI, 0.96–1.06) for men (P = 0.696), and 0.94 (95% CI, 0.90–0.99) for women (P = 0.022) for models that included education.

The reduction in diabetes risk with increased fruit and vegetable intake was greater for women than for men (P = 0.071). Among women, those consuming five or more servings of fruits and vegetables per day had a hazard ratio of 0.61 (95% CI, 0.42–0.88) and a dose response appeared to be present (Table 2). In contrast, no clear effect of eating fruits and vegetables on the risk of diabetes was evident among men.

DISCUSSION

Recommendations about adequate consumption of fruits and vegetables have been based largely on studies of cancer and cardiovascular disease. Our results support the results of only a few prospective [*11–13*] and cross-sectional studies [*24*] that suggest that fruit and vegetable consumption may also decrease the risk for diabetes. The reduction in risk was evident only among women, however. Furthermore, our results suggest that education may be related to diabetes incidence through its positive association with fruit and vegetable consumption.

The effect of several dietary factors on 2-h postload glucose concentrations was examined among 338 Dutch and Finnish men followed for about 20 years [*13*]. Increases in fruit and vegetable intake during the 20-year follow-up period but not baseline fruit and vegetable intake were inversely associated with 2-h postload glucose concentrations. In our study, we followed almost 10,000 men and women and found a significant inverse relationship between fruit and vegetable intake and diabetes incidence among women but not among men. The two studies had similar durations of follow-up and occurred during similar calendar periods. However, they differed in the ages of the cohort members. Furthermore, glucose determinations were done in the two

TABLE 2

Incidence Rates and Hazard Ratios for Fruit and Vegetable Intake and Diabetes Mellitus Incidence among Participants Aged 25–74 Years, NHEFS 1971–1975 to 1992–1993

Fruit and vegetable intake (servings per day)	No. of cases	Person-years	Unadjusted incidence per 100,000 person-years[a]	Age-adjusted incidence per 100,000 person-years[a]	Hazard ratio (95% confidence interval)			
					Unadjusted	Age-adjusted	Multiple-adjusted[b]	Multiple-adjusted[b] (including education)
Total sample (1,018 persons with diabetes /9,665 in sample)								
0	108	12,792	654.1	690.4	1.00	1.00	1.00	1.00
1–4	719	101,057	634.0	636.3	0.96 (0.76–1.23)	0.91 (0.71–1.16)	0.96 (0.74–1.25)	1.01 (0.78–1.29)
≥5	191	38,922	453.0	410.1	0.69 (0.52–0.91)	0.59 (0.45–0.78)	0.73 (0.54–0.98)	0.79 (0.59–1.06)
Men (416 persons with diabetes/3,874 in sample)								
0	37	5,328	490.0	561.2	1.00	1.00	1.00	1.00
1–4	292	37,540	679.9	681.8	1.38 (0.89–2.14)	1.27 (0.81–2.00)	1.20 (0.74–1.95)	1.23 (0.76–1.99)
≥5	87	13,070	574.4	547.7	1.16 (0.70–1.94)	1.01 (0.60–1.71)	1.09 (0.63–1.87)	1.14 (0.67–1.93)
Women (602 persons with diabetes/5,791 in sample)								
0	71	7,464	823.1	840.5	1.00	1.00	1.00	1.00
1–4	427	63,517	595.7	596.6	0.72 (0.52–1.01)	0.69 (0.49–0.97)	0.80 (0.58–1.12)	0.85 (0.62–1.16)
≥5	104	25,852	367.4	334.4	0.45 (0.30–0.65)	0.39 (0.27–0.56)	0.54 (0.36–0.81)	0.61 (0.42–0.88)

[a] Weighted estimate.

[b] Adjusted for age, sex (except sex-specific models), smoking status, systolic blood pressure, cholesterol concentration, use of antihypertensive medication, recreational exercise, nonrecreational activity, alcohol use, and body mass index.

cohorts of the Seven Countries study but not in the NHEFS. In addition, some differences in the types of fruits and vegetables that were consumed are possible due to cultural differences.

Several possible weaknesses in our study deserve to be acknowledged. Persons who consume higher amounts of fruits and vegetables differ from persons who eat fewer fruits and vegetables [25]. Although we adjusted for a number of those known differences, we cannot dismiss the possibility of residual confounding. Furthermore, unknown differences could have affected our findings. We did not have good data about dietary intakes at the individual level. Only a single 24-hour dietary recall was administered to participants. Using this measure of fruit and vegetable intake at baseline has limitations, because it does not address the variability of dietary intake from day to day [26]. Therefore, nondifferential misclassification should drive our results toward the null hypothesis, and our findings may be an underestimate of the true protective effect of fruit and vegetable intake. Thus, adjusting for intakes of total energy and fat was problematical. On the other hand, we could have underestimated the risk if misclassification of both the endpoint and the intake of fruits and vegetables was nondifferential. Although hospital records and death certificates may underreport the diagnosis of diabetes mellitus [27,28], self-reports of diabetes are generally good [29]. About one-third to half of persons with diabetes are unaware of their condition, however [30,31]. Finally, we were unable to differentiate persons with type 1 diabetes mellitus from those with type 2 diabetes mellitus. The vast majority of cases were likely type 2 diabetes mellitus, however.

Our study had several strengths that increase our confidence that our findings were valid. We were able to adjust for a number of risk factors, thus reducing the chance that fruit and vegetable intake was a marker for these risk factors. We were able to examine the relationship over a long follow-up period, thus reducing the chance that the observed effect was a result of undiagnosed diabetes. And we were able to compare findings by sex in a nationally representative sample.

Fruits and vegetables contain numerous phytonutrients that can affect disease risk. Fruits and vegetables are excellent sources of dietary fiber. By increasing the viscosity of contents of the stomach and small intestine, soluble fiber delays the absorption of nutrients, thereby blunting the postprandial rise in blood glucose and insulin [32]. Thus, by improving glucose control and peripheral insulin sensitivity, dietary fiber may reduce the risk of developing diabetes [33,34]. Epidemiologic studies have presented inconsistent findings about the association between fiber and diabetes incidence, however. Some have found some sources of fiber to be protective [35] whereas others found no association between dietary fiber and diabetes mellitus [12,36,37]. Low fiber consumption is also associated with hyperinsulinemia and insulin resistance [37,38].

Fruits and vegetables are good sources of minerals such as magnesium, which may lower the risk of developing diabetes mellitus [12,35]. Magnesium plays an important role in insulin action, and hypomagnesemia is well recognized in persons with diabetes [39]. Hypomagnesemia may impair insulin secretion and promote insulin resistance in the diabetic patient [40,41]. In addition, blood concentrations of magnesium and magnesium intake have been found to be inversely related to insulin concentrations in population-based studies [42,43]. Fruits and vegetables also contain numerous compounds with antioxidant properties such as carotenoids, flavonoids, vitamins, polyphenols, and indoles. Some research suggests that antioxidants could have favorable effects on the pathogenesis of diabetes mellitus [44–48]. Vitamin C intake has been inversely related to the incidence of diabetes and impaired glucose tolerance in a cohort study [13]. Vitamin E concentrations, commonly found in vegetable and seed oils, may be inversely related to the incidence of diabetes mellitus [49] although another study failed to find a significant association after adjustment for various risk factors [50].

Our results from the NHEFS are consistent with those of other studies that have shown an inverse association between fruit and vegetable consumption and diabetes incidence or prevalence. If future studies corroborate these findings, possible mechanisms will need to be elucidated. Because of the growing burden of diabetes in the United States, new approaches to primary and secondary prevention need to be explored. Programs aimed at increasing the fruit and vegetable consumption to reduce the burden of cancer and cardiovascular disease may also favorably affect the diabetes epidemic. The possibility that eating more fruits and vegetables may lower diabetes incidence is an additional reason to adopt this healthy behavior.

REFERENCES

1. Centers for Disease Control and Prevention. National diabetes fact sheet. Atlanta, GA: Centers for Disease Control and Prevention, 1995.
2. Leibson CL, O'Brien PC, Atkinson E, Palumbo PJ, Melton LJ, 3rd. Relative contributions of incidence and survival to increasing prevalence of adult-onset diabetes mellitus: a population-based study. *Am J Epidemiol* 1997;146:12–22.
3. Centers for Disease Control and Prevention. Trends in the prevalence and incidence of self-reported diabetes mellitus—United States, 1980–1994. MMWR Morb Mortal Wkly Rep 1997;46: 1014–18.
4. Kuczmarski RJ, Flegal KM, Campbell SM, Johnson CL. Increasing prevalence of overweight among US adults. JAMA 1994;272: 205–11.
5. Galuska DA, Serdula M, Pamuk E, Siegel P, Byers T. Trends in overweight among U.S. adults from 1987–1993: results from a

multistate telephone survey. Am J Public Health 1996;86: 1729–35.

6. Flegal KM, Carroll MD, Kuczmarski RJ, Johnson CL. Overweight and obesity in the United States: prevalence and trends, 1960–1994. Int J Obes Relat Metab Disord 1998;22:39–47.
7. American Diabetes Association. Economic consequences of diabetes mellitus in the U.S. in 1997. Diabetes Care 1998;21:296–309.
8. West KM. Epidemiology of diabetes and its vascular lesions. New York, Elsevier North-Holland, 1978.
9. Ness AR, Powles JW. Fruits and vegetables and cardiovascular disease: a review. Int J Epidemiol 1997;26:1–12.
10. Steinmetz KA, Potter JD. Vegetables, fruit, and cancer prevention. J Am Diet Assoc 1996;96:1027–39.
11. Snowdon DA, Phillips RL. Does a vegetarian diet reduce the occurrence of diabetes? Am J Public Health 1985;75:507–12.
12. Colditz GA, Manson JE, Stampfer MJ, Rosner B, Willett WC, Speizer FE. Diet and risk of clinical diabetes in women. Am J Clin Nutr 1992;55:1018–23.
13. Feskens EJM, Virtanen SM, Räsänen L, Tuomilehto J, Stengard J, Pekkanen J, *et al.* Dietary factors determining diabetes and impaired glucose tolerance. Diabetes Care 1995;18:1104–12.
14. National Center for Health Statistics. Plan and operation of the Health and Nutrition Examination Survey, United States—1971–1973. Washington, DC: US Government Printing Office, 1973. (Vital and health statistics, Series 1: No. 10a) (DHHS Publication No. (PHS) 79-1310).
15. National Center for Health Statistics. Plan and operation of the Health and Nutrition Examination Survey, United States—1971–1973. Washington, DC: US Government Printing Office, 1977. (Vital and health statistics, Series 1: No. 10b) (DHHS Publication no. (PHS) 79-1310).
16. National Center for Health Statistics. Plan and operation of the HANES I Augmentation Survey of Adults 25–74 years, United States—1974–1975. Washington, DC: US Government Printing Office, 1978. (Vital and health statistics, Series 1: No. 14). (DHHS publication no. (PHS) 78-1314).
17. National Center for Health Statistics. Plan and operation of the NHANES I Epidemiologic Followup Study, 1987. Washington, DC: US Government Printing Office, 1992. (Vital and health statistics, Series 1: No. 27) (DHHS Publication No. (PHS) 92-1303).
18. US Department of Agriculture. Agriculture Handbook No. 8, Composition of foods, raw, processed, prepared. Washington, DC: USDA, 1963.
19. Church CF, Bowes HN. Bowes and Church's food values and portions commonly used. Philadelphia, PA: Lippincott, 1966.
20. McLaughlin JK, Dietz MS, Mehl ES, Blot WJ. Reliability of surrogate information on cigarette smoking by type of informant. Am J Epidemiol 1987;126:144–46.
21. Machlin SR, Kleinman JC, Madans JH. Validity of mortality analysis based on retrospective smoking information. Stat Med 1989;8:997–1009.
22. Shah BV, Barnwell BG, Bieler GS. SUDAAN user's manual, Version 7.5. Research Triangle Park, NC: Research Triangle Institute, 1997.
23. SAS Institute. SAS Technical Report P-229. Cary, NC: SAS Institute, 1992.
24. Gittelsohn J, Wolever TM, Harris SB, Harris-Giraldo R, Hanley AJ, Zinman B. Specific patterns of food consumption and preparation are associated with diabetes and obesity in a Native Canadian community. J Nutr 1998;128:541–47.
25. Serdula MK, Byers T, Mokdad AH, Simoes E, Mendlein JM, Coates RJ. The association between fruit and vegetable intake and chronic disease risk factors. Epidemiology 1996;7:161–65.
26. Willett W. Nutritional epidemiology. New York: Oxford Univ. Press, 1990.
27. Bild DE, Stevenson JM. Frequency of recording of diabetes on US death certificates: analysis of the 1986 National Mortality Followback Survey. J Clin Epidemiol 1991;45:275–81.
28. Ford ES, Wetterhall S. The validity of diabetes on hospital discharge diagnoses. Diabetes 1991;40(Suppl 1):449A. [Abstract]
29. Harlow SD, Linet MS. Agreement between questionnaire data and medical records: the evidence for accuracy of recall. Am J Epidemiol 1989;129:233–48.
30. Harris MI, Hadden WC, Knowler WC, Bennett PH. Prevalence of diabetes and impaired glucose tolerance and plasma glucose levels in U.S. population aged 20–74 yr. Diabetes 1987;36: 523–34.
31. Harris MI, Flegal KM, Cowie CC, Eberhardt MS, Goldstein DE, Little RR, *et al.* Prevalence of diabetes, impaired fasting glucose, and impaired glucose tolerance in U.S. adults. The Third National Health and Nutrition Examination Survey, 1988–1994. Diabetes Care 1998;21:518–24.
32. Wursch P, Pi-Sunyer FX. The role of viscous soluble fiber in the metabolic control of diabetes. A review with special emphasis on cereals rich in beta-glucan. Diabetes Care 1997;20:1774–80.
33. Trowell HC. Dietary fiber hypothesis of the etiology of diabetes mellitus. Diabetes 1975;24:762–65.
34. Anderson JW, Akanji AO. Dietary fiber—an overview. Diabetes Care 1991;14:1126–31.
35. Salmeron J, Ascherio A, Rimm EB, Colditz GA, Spiegelman D, Jenkins DJ, *et al.* Dietary fiber, glycemic load, and risk of NIDDM in men. Diabetes Care 1997;20:545–50.
36. Feskens EJ, Bowles CH, Kromhout D. Carbohydrate intake and body mass index in relation to the risk of glucose intolerance in an elderly population. Am J Clin Nutr 1991;54:136–40.
37. Marshall JA, Weiss NS, Hamman RF. The role of dietary fiber in the etiology of non-insulin-dependent diabetes mellitus. The San Luis Valley Diabetes Study. Ann Epidemiol 1993;3:18–26.
38. Feskens EJ, Loeber JG, Kromhout D. Diet and physical activity as determinants of hyperinsulinemia: the Zutphen Elderly Study. Am J Epidemiol 1994;140:350–60.
39. Paolisso G, Scheen A, Onofrio FD, Lefegbre P. Magnesium and glucose homeostasis. Diabetologia 1990;33:511–14.
40. Scheen JP. Magnesium deficiency and diabetes mellitus. Magnes Trace Elem 1991-92;10:215–19.
41. Paolisso G, Sgambato S, Gambardella A, Pizza G, Tesauro P, Varricchio M, et al. Daily magnesium supplements improve glucose handling in elderly subjects. Am J Clin Nutr 1992;55: 1161–67.
42. Manolio TA, Savage PJ, Burke GL, Hilner JE, Liu K, Orchard TJ, *et al.* Correlates of fasting insulin levels in young adults: the CARDIA study. J Clin Epidemiol 1991;44:571–78.
43. Ma J, Folsom AR, Melnick SL, Eckfeldt JH, Sharrett AR, Nabulsi AA, *et al.* Associations of serum and dietary magnesium with cardiovascular disease, hypertension, diabetes, insulin, and carotid arterial wall thickness: the ARIC Study. J Clin Epidemiol 1995;48:927–40.
44. Oberly LW. Free radicals and diabetes. Free Radic Biol Med 1988;5:113–24.
45. Paolisso G, D'Amore A, Volpe C, Balbi V, Saccomanno F, Galzerano D, *et al.* Evidence for a relationship between free radicals and insulin action in the elderly. Metabolism 1993;42:659–63.
46. Paolisso G, DAmore A, Gugliano D, Ceriello A, Varrichio M, DOnofrio F. Pharmacologic doses of vitamin E improve insulin action in healthy subjects and non-insulin-dependent diabetic patients. Am J Clin Nutr 1993;57:650–56.

47. Wolff SP. Diabetes mellitus and free radicals. Br Med Bull 1993;49:642–52.

48. Ford ES, Will JC, Bowman BA, Narayan K. Diabetes mellitus and serum carotenoids: findings from a national population-based survey. Am J Epidemiol 1999;149:168–76.

49. Salonen JT, Nyyssonen K, Tuomainen TP, Maenpaa PH, Korpela H, Kaplan GA, *et al.* Increased risk of non-insulin dependent diabetes mellitus at low plasma vitamin E concentrations: a four year follow up study in men. Br Med J 1995;311:1124–27.

50. Reunanen A, Knekt P, Aaran RK, Aromaa A. Serum antioxidants and risk of non-insulin dependent diabetes mellitus. Eur J Clin Nutr 1998;52:89–93.