Potato and french fry consumption and risk of type 2 diabetes in women[1–3]

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ABSTRACT

Background: Potatoes, a high glycemic form of carbohydrate, are hypothesized to increase insulin resistance and risk of type 2 diabetes.

Objective: The objective was to examine prospectively the relation between potato consumption and the risk of type 2 diabetes.

Design: We conducted a prospective study of 84 555 women in the Nurses' Health Study. At baseline, the women were aged 34–59 y, had no history of chronic disease, and completed a validated food-frequency questionnaire. The participants were followed for 20 y with repeated assessment of diet.

Results: We documented 4496 new cases of type 2 diabetes. Potato and french fry consumption were both positively associated with risk of type 2 diabetes after adjustment for age and dietary and nondietary factors. The multivariate relative risk (RR) in a comparison between the highest and the lowest quintile of potato intake was 1.14 (95% CI: 1.02, 1.26; P for trend = 0.009). The multivariate RR in a comparison between the highest and the lowest quintile of french fry intake was 1.21 (95% CI: 1.09, 1.33; P for trend < 0.0001). The RR of type 2 diabetes was 1.18 (95% CI: 1.03, 1.35) for 1 daily serving of potatoes and 1.16 (95% CI: 1.05, 1.29) for 2 weekly servings of french fries. The RR of type 2 diabetes for substituting 1 serving potatoes/d for 1 serving whole grains/d was 1.30 (95% CI: 1.08, 1.57). The association between potato consumption and risk of type 2 diabetes was more pronounced in obese women.

Conclusions: Our findings suggest a modest positive association between the consumption of potatoes and the risk of type 2 diabetes in women. This association was more pronounced when potatoes were substituted for whole grains. *Am J Clin Nutr* 2006;83:284–90.

KEY WORDS Potato, french fry, type 2 diabetes, glycemic load, glycemic index, Nurses' Health Study, women

INTRODUCTION

The role of potatoes in a diet aimed at reducing the burden of chronic disease has been controversial. In both the 1992 US Department of Agriculture (USDA) Food Guide Pyramid (1) and the 2005 revision (2), potatoes were included in the vegetable category as a food to be encouraged. Potatoes were also emphasized as a healthful food by a variety of professional and medical organizations, including the American Dietetic Association and the American Heart Association (3, 4). However, in a review by the World Cancer Research Fund (5), potatoes did not share the beneficial relation with cancer incidence seen with other vegetables. Concerns were also raised about possible adverse effects of high potato consumption on the risk of type 2 diabetes because they contain large amounts of rapidly absorbed starch and thus are important contributors to dietary glycemic index (GI) and load.

The GI of a carbohydrate is a measure of how much that food raises blood glucose compared with a standard carbohydrate, usually glucose or white bread (6). Potatoes and potato products are widely consumed in the United States, with a per capita consumption of 61.2 kg (135 pounds) in 2002 (7). White potatoes have both a high GI and a high glycemic load, which takes into account the amount of carbohydrate in addition to its GI (8). Several studies have shown a positive association between a high glycemic diet and the risk of type 2 diabetes (9–11), whereas others with less comprehensive dietary data have not observed this association (12, 13). In the present study, we examined prospectively the association between the consumption of potato products and the incidence of type 2 diabetes in women from the Nurses' Health Study. Because a person's response to a given carbohydrate load may be influenced by underlying insulin resistance, which is common in those with higher body mass indexes (BMIs; in kg/m^2) and lower levels of physical activity (14, 15), we examined the association between potato products and the risk of type 2 diabetes by stratifying on these factors. We also compared consumption of potatoes with whole grains, which are related to a lower risk of type 2 diabetes and are encouraged by the 2005 Dietary Guidelines, and to refined starches, which are limited by the new guidelines.

SUBJECTS AND METHODS

Study population

The Nurses' Health Study was initiated in 1976 when 121 700 female registered nurses aged 30–55 y completed a mailed questionnaire. Ninety-eight percent of these women were white,

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which reflected the ethnic composition of US registered nurses at the time. Since 1976, information on disease status as well as lifestyle factors has been collected every 2 y. Diet was assessed by means of a semiquantitative food-frequency questionnaire (FFQ) in 1980, 1984, 1986, 1990, 1994, and 1998.

For this investigation, we excluded all women at baseline who left ≥10 food items blank or had implausibly high (>3500 kcal) or low (<500 kcal) energy intakes on the semiquantitative FFQ. We also excluded women with a history of diabetes, cancer (not including nonmelanoma skin cancer), or cardiovascular disease at baseline because these diseases can cause alterations in diets. After these exclusions, 84 555 women remained in this investigation. The participants were followed for 20 y (1980–2000). The study was conducted according to the ethical guidelines of Brigham and Women's Hospital, Boston, MA.

Dietary assessment

At baseline, the semiquantitative FFQ contained 61 food items and was revised in subsequent cycles to include about twice that number (16, 17). The study participants reported the average frequency of consumption of foods with a commonly used portion size throughout the previous year. The validity and reproducibility of the questionnaire are documented elsewhere (17).

We asked each participant how often, on average, they had consumed potatoes [serving size: 1 baked or 237 mL (1 cup) mashed potato] in the previous year. We also asked how often each participant had consumed french fried potatoes during the previous year [serving size: 113 g (4 ounces)]. The possible responses ranged from never or <1/mo to ≥6 times/d. When corrected for week-to-week variations in diet records that were used to assess validity, the correlation between the 1980 FFQ and the diet records was 0.66 for potatoes and 0.60 for french fries (18).

Other nutrient values such as *trans* fat, saturated fat, polyunsaturated fat, and cereal fiber were computed by multiplying the frequency of consumption of each food by the nutrient content of the portion and then adding these products across each food item. All food composition values were obtained from the Harvard University Food Composition Database, which was derived from USDA sources (19). This database was further supplemented with the manufacturer's information.

Measurement of nondietary factors

In 1982 and 1988, the women provided information about family history of diabetes in first-degree relatives. The participants also provided information on the use of postmenopausal hormones, smoking status, and body weight every 2 y throughout the follow-up. The correlation coefficient between self-reported body weight and measured weight was 0.96 (20).

The participants reported specific physical activities in hours per week in 1980, 1982, 1986, 1988, 1992, 1996, and 1998. From each questionnaire we calculated the average number of hours per week spent in moderate or vigorous activity, including brisk walking, vigorous sports, jogging, cycling, heavy gardening, and housework.

Outcome ascertainment

The outcome of the present study was incident type 2 diabetes mellitus. If a participant reported a diagnosis of diabetes on any of the 2-y follow-up questionnaires, a supplementary questionnaire about symptoms, diagnostic testing, and treatment was mailed. A diagnosis of type 2 diabetes was defined by at least one of the following criteria reported on the supplemental questionnaire: *1*) ≥1 classic symptoms (excessive thirst, polyuria, hunger, or weight loss) plus a fasting plasma glucose concentration of ≥140 mg/dL (7.8 mmol/L) or a random plasma glucose concentration of ≥200 mg/dL (11.1 mmol/L); *2*) ≥2 elevated plasma glucose concentrations on different occasions [fasting: ≥140 mg/dL (7.8 mmol/L), random ≥200 mg/dL (11.1 mmol/L)] or random ≥200 mg/dL (11.1 mmol/L) after ≥2 h oral-glucose-tolerance testing, in the absence of symptoms; or *3*) treatment with hypoglycemic medications (insulin or oral hypoglycemic agents). These criteria correspond to those of the National Diabetes Data Group (21) because most cases were diagnosed before 1997. We excluded women classified as having only gestational diabetes as well as those with type 1 diabetes. In the Nurses' Health Study, the supplemental questionnaire was highly reliable in obtaining confirmation of a diabetes diagnosis. In a random sample of 84 women classified as having type 2 diabetes according to the supplemental questionnaire, medical records were available for 62 of them. An endocrinologist who was blinded to the supplemental questionnaire data reviewed the records and confirmed the diagnosis of type 2 diabetes in 61 of the 62 (98%) women (22).

Statistical analysis

Each participant contributed follow-up time from the date of returning the 1980 baseline questionnaire to the date of diagnosis of type 2 diabetes, 1 June 2000, or death. Women were excluded from additional follow-up once they were diagnosed with diabetes. We divided the participants into 5 categories (quintiles) according to the frequency of potato consumption. To represent long-term intake and to reduce measurement error, the cumulative frequency of consumption was calculated (23). For example, potato intake from the 1980 questionnaire was related to diabetes incidence between 1980 and 1984, and potato intake from the average of the 1980 and 1984 questionnaires was related to diabetes incidence between 1984 and 1986. We also created quintiles of cumulative french fry consumption. Incidence rates for type 2 diabetes were calculated by dividing cases by the person-years of follow-up for each quintile of potato intake. Relative risks (RRs) of type 2 diabetes were calculated by dividing the rate of occurrence of diabetes in each quintile by the rate in the first (lowest) quintile. We used Cox proportional hazards models (24) to adjust for potentially confounding variables, which included BMI, family history of diabetes, smoking, postmenopausal hormone use, and physical activity. We additionally adjusted for dietary variables, including *trans* fat, the ratio of polyunsaturated fat to saturated fat, cereal fiber, and total calories. We also considered potatoes and whole grains as continuous variables in the same model. The difference in the coefficients from this multivariate model was used to estimate the RR and 95% CI for substituting 1 serving potatoes/d for 1 serving whole grains and refined grains/d.

All *P* values were two-sided. Tests for trend were examined by using the median value for each category of potato consumption, which was analyzed as a continuous variable in the regression models. All statistical analyses were performed with SAS version 8.2 software (SAS Institute, Cary, NC).

TABLE 1
Age-standardized year 1990 characteristics according to french fry and potato consumption in 84 555 participants in the Nurses' Health Study[1]

	Potato consumption			French fry consumption		
Variable	Quintile 1	Quintile 3	Quintile 5	Quintile 1	Quintile 3	Quintile 5
Median intake (servings/d)	0.07	0.29	0.63	0	0.05	0.14
Age (y)	56.0 ± 7.0[2]	56.0 ± 7.9	56.1 ± 7.5	56.2 ± 6.8	56.1 ± 6.8	55.9 ± 7.7
BMI (kg/m^2)	25.5 ± 4.7	25.7 ± 4.7	25.4 ± 5.0	25.0 ± 4.1	25.5 ± 4.1	26.0 ± 5.1
Family history of diabetes (%)	23	26	24	22	26	24
Postmenopausal hormone use (%)	27	28	24	28	28	24
Physical activity (h/wk)	3.4 ± 2.2	3.2 ± 1.5	3.0 ± 2.3	3.6 ± 2.5	3.2 ± 2.5	2.9 ± 2.4
Current smokers (%)	18	17	19	15	17	23
Alcohol consumption (g/d)	5.2 ± 8.9	5.30 ± 10.3	5.0 ± 9.1	5.2 ± 9.4	5.4 ± 10.2	5.0 ± 9.9
Calories (kcal)	1463 ± 474.9	1767 ± 486.3	1981 ± 530.0	1612 ± 490.3	1724 ± 501.8	1908 ± 548.8
Polyunsaturated fat (% of energy)	5.9 ± 2.0	5.9 ± 1.5	5.9 ± 1.1	5.8 ± 1.2	5.9 ± 1.3	6.0 ± 1.1
trans Fat (% of energy)	1.4 ± 1.0	1.5 ± 0.6	1.6 ± 1.1	1.2 ± 0.5	1.5 ± 0.5	1.8 ± 1.1
Saturated fat (% of energy)	10.4 ± 3.0	10.7 ± 2.9	10.8 ± 2.3	9.8 ± 2.3	10.6 ± 2.6	11.5 ± 2.2
Glycemic load[3]	95 ± 38.7	117 ± 39.8	135 ± 43.0	111 ± 41.1	114 ± 40.8	126 ± 44.0
Glycemic index[3]	51.3 ± 4.0	52.9 ± 2.9	54.1 ± 3.4	51.8 ± 3.5	52.7 ± 3.8	53.8 ± 3.3
Cereal fiber (g/d)	4.9 ± 4.0	5.6 ± 2.9	6.0 ± 3.4	6.0 ± 4.7	5.5 ± 3.8	5.3 ± 3.3
Fruit and vegetables (servings/d)	4.8 ± 2.3	5.1 ± 1.6	5.4 ± 2.5	5.6 ± 2.7	5.1 ± 1.4	4.8 ± 2.6
Coffee (cups/d)	1.9 ± 1.2	1.9 ± 1.6	1.9 ± 1.2	1.8 ± 1.4	1.8 ± 1.4	2.0 ± 1.3
Magnesium intake (mg/d)	313 ± 86.6	301 ± 74.5	288 ± 68.8	326 ± 80.4	303 ± 75.9	276 ± 66.8
Multivitamin use (%)	29	33	29	31	34	25
Red meat (servings/d)[4]	1.1 ± 1.2	1.2 ± 0.6	1.5 ± 1.2	1.1 ± 1.4	1.2 ± 0.6	1.6 ± 1.3
Whole grains (servings/d)	1.3 ± 1.0	1.5 ± 1.5	1.6 ± 1.1	1.7 ± 1.2	1.5 ± 1.3	1.3 ± 1.1
Refined grains (servings/d)	1.6 ± 1.0	2.1 ± 1.5	2.5 ± 1.1	1.7 ± 1.2	2.0 ± 1.3	2.5 ± 2.2
Nuts (servings/d)	0.1 ± 0.2	0.1 ± 0.2	0.2 ± 0.2	0.2 ± 0.3	0.1 ± 0.2	0.2 ± 0.2

[1] Tests for trend (based on ordinal variables containing median values for each quintile) were all significant ($P < 0.05$), except for age, alcohol consumption, coffee consumption, and family history of type 2 diabetes for potatoes.
[2] $\bar{x}$ ± SD (all such values).
[3] Glucose used as reference for calculations of glycemic index and glycemic load.
[4] Composite score of beef, pork, and lamb as a main dish or mixed dish, and hamburgers, hot dogs, bacon, and processed meats.

RESULTS

At baseline in 1980, potato consumption ranged from a median of 0.07 serving/d in the first quintile to 0.79 serving/d in the highest quintile. French fry intake was considerably less; the median for the lowest quintile was zero servings, whereas the median in the highest quintile was just 0.14 serving/d. Potato and french fry consumption was largely consistent over time (overall $\bar{x}$± SD: 0.32 ± 0.23 servings potatoes/d for potato and 0.07 ± 0.08 servings french fries/d). This amount of consumption is similar to that of the general US population during the years 1980–2000 (25). The women who consumed more potatoes tended to have a higher dietary glycemic load and higher intakes of red meat, refined grain, and total calories. They were also less likely to take postmenopausal hormone therapy. Family history of diabetes, *trans* fat intake, BMI, and physical activity were not significantly different across quintiles (**Table 1**). The women who consumed more french fries tended to have a higher dietary glycemic load and higher intakes of red meat, refined grain, and total calories. They were more likely to smoke but were less likely to take multivitamins and postmenopausal hormone therapy. Family history of diabetes, *trans* fat intake, BMI, and physical activity were not significantly different across quintiles (Table 1). Because of the length of follow-up (20 y), the characteristics in Table 1 are presented as the midpoint of follow-up (1990) rather than baseline (1980).

During the 20 y of follow-up (1 597 429 person-years), we documented 4496 cases of type 2 diabetes. For potatoes, the age-adjusted RR of type 2 diabetes was 1.13 (95% CI: 1.03, 1.25) in a comparison between the women in the fifth quintile and those in the first quintile (P for trend = 0.02) (**Table 2**). In multivariate models, the addition of BMI as a categorical variable (10 categories) slightly increased the RR to 1.18 (95% CI: 1.07, 1.30; P for trend = 0.0003). The RR did not change appreciably after additional control for smoking, family history of diabetes, physical activity, and postmenopausal hormone use (1.17; 95% CI: 1.06, 1.29; P for trend = 0.0004). After additional control for other dietary variables (*trans* fat intake, polyunsaturated fat-to-saturated fat ratio, total calories, and cereal fiber), the RR was slightly attenuated to 1.14 (95% CI: 1.02, 1.26; P for trend = 0.009). Additional adjustment for consumption of nuts, coffee, alcohol, fruit, vegetables, whole grains, and soft drinks did not appreciably change the results.

The age-adjusted RR that compared the highest quintile of french fry intake (0.14 servings/d) with the lowest quintile (0 servings/d) was 1.65 (95% CI: 1.50, 1.80; P for trend < 0.0001) (Table 2). The addition of BMI to the model attenuated the RR to 1.29 (95% CI: 1.17, 1.41; P for trend < 0.0001). The RR was further attenuated to 1.25 (95% CI: 1.14, 1.37, P for trend < 0.0001) after additional adjustment for smoking, family history, physical activity, and postmenopausal hormone use. After additional control for dietary variables such as *trans* fat intake, the polyunsaturated fat-to-saturated fat ratio, total calories, and cereal fiber, the RR was 1.21 (95% CI: 1.09, 1.33; P for trend < 0.0001). Additional adjustment for consumption of nuts, coffee,

TABLE 2
Relative risk of type 2 diabetes in 84 555 women according to frequency of potato and french fry consumption

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*P* for trend[1]	Servings (potato: 1/d; french fry: 2/wk)
Potato							
Cases (*n*)	761	830	1125	904	876	—	—
Person-years	309 204	314 139	347 647	348 350	278 090	—	—
Median servings/d	0.07	0.14	0.29	0.43	0.63	—	—
Range	0–0.11	0.12–0.2	0.21–0.36	0.37–0.43	0.44–2.50	—	—
Age-adjusted RR (95% CI)	1.0	1.07 (0.97, 1.18)	1.13 (1.03, 1.24)	1.11 (1.01, 1.23)	1.13 (1.03, 1.25)	0.02	1.16 (1.02, 1.32)
Age and BMI (95% CI)	1.0	1.05 (0.95, 1.16)	1.09 (0.99, 1.20)	1.14 (1.04, 1.26)	1.18 (1.07, 1.30)	0.0003	1.25 (1.10, 1.42)
Age and nondietary factors (95% CI)[2]	1.0	1.05 (0.95, 1.16)	1.06 (0.97, 1.17)	1.15 (1.04, 1.26)	1.17 (1.06, 1.29)	0.0004	1.25 (1.10, 1.42)
Age, nondietary factors, and dietary factors (95% CI)[3]	1.0	1.05 (0.95, 1.16)	1.07 (0.97, 1.18)	1.13 (1.02, 1.25)	1.14 (1.02, 1.26)	0.009	1.18 (1.03, 1.35)
French fries							
Cases (*n*)[4]	986	538	808	1168	988	—	—
Person-years	433 141	170 621	243 386	428 747	320 843	—	—
Median servings/d	0	0.02	0.05	0.07	0.14	—	—
Range	0	0.01–0.03	0.04–0.06	0.07–0.10	0.11–1.0	—	—
Age-adjusted RR (95% CI)	1.0	1.13 (1.01, 1.26)	1.32 (1.20, 1.45)	1.37 (1.26, 1.50)	1.65 (1.50, 1.80)	<0.0001	1.59 (1.46, 1.74)
Age and BMI (95% CI)	1.0	1.03 (0.92, 1.15)	1.17 (1.06, 1.28)	1.17 (1.07, 1.27)	1.29 (1.17, 1.41)	<0.0001	1.25 (1.14, 1.38)
Age and nondietary factors (95% CI)[2]	1.0	1.0 (0.90, 1.11)	1.14 (1.03, 1.25)	1.14 (1.04, 1.24)	1.25 (1.14, 1.37)	<0.0001	1.24 (1.12, 1.36)
Age, nondietary factors, and dietary factors (95% CI)[3]	1.0	1.01 (0.90, 1.12)	1.14 (1.03, 1.25)	1.12 (1.02, 1.22)	1.21 (1.09, 1.33)	<0.0001	1.16 (1.05, 1.29)

[1] Based on ordinal variable containing median value for each quintile.
[2] Cox proportional hazard model adjusted for age in 5-y categories, BMI (<22, 22–22.9, 23–23.9, 24–24.9, 25–27.9, 28–29.9, 30–31.9,32–33.9, 34–39.9, or >40 kg/m^2), family history of diabetes in a first-degree relative (yes or no), smoking (never, past, or current smoking 1–14, 15–25, >25 cigarettes/d), postmenopausal hormone use (never, current use, or past use), and moderate to vigorous physical activity (<1, 1–2, 2–4, 4–7, >7 h/wk).
[3] Adjusted for the above variables and total calories, cereal fiber (g/d), *trans* fat (% of energy), and polyunsaturated fat:saturated fat.
[4] Because participants with missing baseline potato and french fry data were excluded from the analyses, the number of cases and person-years slightly vary between the 2 analyses.

alcohol, fruit, vegetables, whole grains, and soft drinks did not appreciably change the results.

In additional analyses that used potato consumption as a continuous variable, the multivariate RR of type 2 diabetes for consuming 1 serving potatoes/d [237 mL (1 cup) mashed or 1 baked] was 1.18 (95% CI: 1.03, 1.35) (Table 2). The multivariate RR for 2 [113 g (4 oz)] servings french fries/wk was 1.16 (95% CI: 1.05, 1.29) (Table 2). Furthermore, the RR of substituting 1 serving potatoes/d for 1 serving whole grains/d was 1.30 (95% CI: 1.08, 1.57). The RR of substituting 1 serving potatoes/d for 1 serving refined grains/d was 1.22 (95% CI: 1.01, 1.47).

In stratified analyses, the association between potato consumption and diabetes was statistically significant in obese women but not in nonobese women (P for interaction = 0.01) (**Table 3**). This was not observed for french fry consumption. No significant interaction was observed between the consumption of potatoes or french fries and physical activity or family history of type 2 diabetes.

In our cohort, red meat was significantly correlated with consumption of potatoes ($r = 0.24$, $P < 0.0001$) and french fries ($r = 0.29$, $P < 0.0001$). When red meat consumption was added to the multivariate models, the association was slightly attenuated. For potato intake, the RR of type 2 diabetes in a comparison of the fifth quintile with the first quintile was 1.12 (95% CI: 1.01, 1.25; P for trend = 0.02). A similar attenuation in RR was seen for french fries (1.19; 95% CI: 1.07, 1.31; P for trend = 0.0004).

To examine whether the associations between potatoes and french fry intake were mediated through a higher glycemic load, we added glycemic load to the multivariate models. After adjustment for glycemic load, the RRs in a comparison of extreme quintiles were 1.06 (95% CI: 0.95, 1.18; P for trend = 0.24) for potatoes and 1.15 (95% CI: 1.04, 1.27; P for trend = 0.005) for french fries.

DISCUSSION

We found that the intakes of potatoes and french fries were positively associated with the incidence of type 2 diabetes in this large prospective cohort of women. The increased risk was more pronounced when potatoes replaced whole-grain products in the diet. This association was independent of known risk factors for

TABLE 3
Multivariate relative risks of type 2 diabetes in 84 555 women according to frequency of potato and french fry consumption, stratified by BMI[1]

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*P* for trend[2]
Potato						
BMI <30 (n = 1958 cases)[3]	1.0	0.97 (0.84, 1.13)	1.01 (0.88, 1.17)	0.98 (0.85, 1.14)	0.95 (0.82, 1.11)	0.58
BMI ≥30 (n = 2538 cases)	1.0	1.12 (0.98, 1.28)	1.12 (0.98, 1.27)	1.20 (1.05, 1.38)	1.22 (1.06, 1.41)	0.007
French fries[4]						
BMI <30 (3) (n = 1950 cases)	1.0	1.14 (0.97, 1.33)	1.17 (1.01, 1.35)	1.14 (1.0, 1.30)	1.34 (1.15, 1.55)	0.0003
BMI ≥ 30 (n = 2540 cases)	1.0	0.94 (0.80, 1.09)	1.16 (1.02, 1.33)	1.15 (1.01, 1.29)	1.19 (1.04, 1.36)	0.003

[1] Cox proportional hazards model adjusted for age in 5-y categories, family history of diabetes in a first-degree relative (yes or no), smoking (never, past, or current smoking 1–14, 15–25, >25 cigarettes/d), postmenopausal hormone use (never, current use, or past use), physical activity (<1, 1–2, 2–4, 4–7, >7 h/wk), total calories, cereal fiber (g/d), *trans* fat (% of energy), and polyunsaturated fat: saturated fat.

[2] Based on ordinal variable containing median value for each quintile.

[3] P for interaction < 0.05

[4] Because participants with missing baseline potato and french fry data were excluded from the analyses, the number of cases and person-years slightly vary between the 2 analyses.

type 2 diabetes, including family history, age, BMI, physical activity, smoking status, postmenopausal hormone use, and dietary factors. As expected, the positive association between potato consumption and the risk of type 2 diabetes was seen primarily in obese and sedentary women. These participants are more likely to have underlying insulin resistance, which may exacerbate the adverse metabolic effects of higher glycemic carbohydrates (14, 15).

French fries are usually composed of white potatoes and partially hydrogenated oils containing *trans* fat. In our cohort, *trans* fat was positively associated with an increased risk of type 2 diabetes (26). This may partially explain why french fries had a stronger association with type 2 diabetes than did potatoes. However, adjustment for *trans* fat did not eliminate the association with french fries.

The 20-y follow-up with updated dietary data and large sample size provided adequate power for the present study. Bias was minimized by the prospective design and the high follow-up rate. Some misclassification of intakes of potatoes and french fries existed because diet was assessed by self-report. However, this misclassification would tend to bias the results toward the null and therefore would not likely account for these results. Measurement error in assessing long-term diet was reduced in the present analyses by using the average of all available measurements of diet up to the start of each 2-y follow-up interval (27, 28).

Although we assessed and adjusted for a variety of potential confounding variables, we cannot rule out the possibility of residual confounding, especially because the observed association between potatoes and the risk of type 2 diabetes was modest in the present study. This population consisted of mostly white women with some college education. Although this homogeneity increases the internal validity of the study by reducing confounding by factors that are difficult to measure, the association between potatoes and the risk of type 2 diabetes in women of other racial and educational backgrounds should also be evaluated. Precooking potatoes and eating them cold days later may significantly reduce the GI (29). Although we did not assess cooking methods in the FFQ, we believe most of the potatoes consumed in our cohort were eaten hot shortly after preparation.

The high glycemic load of potato products is a likely mechanism by which they may increase the risk of type 2 diabetes. In our analyses, adjustment for glycemic load attenuated the associations between potatoes and diabetes risk, which suggests that most or all of the association was mediated through the high glycemic load. However, a significant association persisted for french fries after adjustment for glycemic load, which probably suggests that other components, including *trans* fat, also contribute to the adverse effects of french fries. Several prospective studies have supported a positive association between a high GI or glycemic load diet and the risk of type 2 diabetes. Salmeron et al (9, 10) conducted 2 prospective cohort investigations about GI and type 2 diabetes. In the Nurses' Health Study, the women in the highest quintile of GI had a RR of type 2 diabetes of 1.37 (95% CI: 1.09, 1.71) compared with those in the lowest quintile. The glycemic load was also positively associated with risk (1.47; 95% CI: 1.16, 1.86) (9), which was confirmed in an extended follow-up of this population (30). In the all-male Health Professionals Follow-up cohort, the GI was positively associated with the risk of type 2 diabetes. Men in the highest quintile had a RR of 1.37 (95% CI: 1.02, 1.83) compared with men in the lowest quintile (10). Furthermore, in the younger Nurses' Health II cohort, GI was significantly associated with an increased risk of type 2 diabetes, with an RR of 1.59 (95% CI: 1.21, 2.10) in a comparison of the fifth quintile with the first quintile (11).

In contrast, Meyer et al (13) reported no association between GI and the risk of type 2 diabetes in the Iowa Women's Health Study. However, only baseline nutritional data were available for the 6-y follow-up, and the validity of self-reported diabetes was only moderate (64%). These factors may have lead to an underestimation of the association. Stevens et al (12) observed no association between GI or glycemic load and the incidence of type 2 diabetes in a 9-y cohort study of 12 251 adults. However, after adjustment for cereal fiber, the association between glycemic load and type 2 diabetes became borderline significant in whites ($P = 0.07$). The use of a single baseline 66-item FFQ may have attenuated the results. When we used only baseline data in our cohort, the RR for potatoes was attenuated to 1.10 (95% CI: 0.99, 1.22; P for trend = 0.23).

Few studies have examined the relation between the consumption of potatoes or french fries and the risk of type 2 diabetes. In a recent 8.8-y prospective investigation in the Women's Health Study, Liu et al (31) found a small and nonsignificant positive association between potato intake and the risk of type 2 diabetes

(n = 1353 cases) in overweight women (RR in a comparison of the highest with the lowest quintiles = 1.14; 95% CI: 0 0.95, 1.36: P for trend = 0.12).

Several mechanisms have been proposed to explain how high glycemic carbohydrates may increase the risk of type 2 diabetes. Most stem from the greater increase in blood glucose and insulin concentrations with high glycemic carbohydrates in comparison to lower glycemic carbohydrates. High glucose concentrations may cause oxidative stress to pancreatic β cells or glycosylation of proteins and key enzymes responsible for metabolic processes (32). This may lead to β-cell dysfunction and ultimately to type 2 diabetes. This would be manifested as β-cell exhaustion (14, 15, 33), when production of insulin can no longer meet the demand. A recent investigation in rats showed a severely disorganized architecture and extensive fibrosis of pancreatic islets after 18 wk on a high glycemic diet (34).

Another potential mechanism is that of lipotoxicity (32, 35–39). Four to 6 h after consumption of a high glycemic carbohydrate, low concentrations of metabolic fuels trigger a counterregulatory hormone response that attempts to restore euglycemia by stimulating glycogenolytic and gluconeogenic pathways and elevating free fatty acid concentrations (35). This elevation in free fatty acids may increase insulin resistance by decreasing insulin-stimulated glucose uptake (36, 37).

The importance of the GI when carbohydrates are consumed as part of a mixed meal has been controversial. One investigation reported that when carbohydrates were consumed with fat and protein, the GI was no longer a significant predictor of blood glucose concentrations (40). However, a larger number of published reports have shown that the GI remains discriminating even in mixed meals (41–48). Therefore, the weight of evidence suggests that even when incorporated into a mixed meal, the GI of carbohydrate remains a significant predictor of blood glucose, although this effect may be somewhat attenuated. Even though the GI of the potatoes in a mixed meal is reduced, this would not affect the relative ranking of GIs between different persons. Also, control for dietary fat and protein did not substantially change our results.

White potatoes and french fries are large components of a "Western pattern" diet. This dietary pattern is characterized by a high consumption of red meat, refined grains, processed meat, high-fat dairy products, desserts, high-sugar drinks, and eggs, as well as french fries and potatoes. A Western pattern diet previously predicted a risk of type 2 diabetes (49). Thus, we cannot completely separate the effects of potatoes and french fries from the effects of the overall Western dietary pattern.

In conclusion, a higher consumption of potatoes and french fries was associated with a modestly increased risk of type 2 diabetes in this large cohort of women. These data support a potential benefit from limiting the consumption of these foods in reducing the risk of type 2 diabetes. Substitution of these sources of carbohydrate with lower glycemic, high-fiber forms of carbohydrates such as whole grains should be encouraged.

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