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Vegetable but Not Fruit Consumption Reduces the Risk of Type 2 Diabetes in Chinese Women[1,2]

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Abstract

We examined associations between fruit and vegetable intake and the incidence of type 2 diabetes (T2D) in a population-based prospective study of 64,191 women with no history of T2D or other chronic diseases at study recruitment and with valid dietary information. Dietary intake was assessed by in-person interviews using a validated FFQ. During 297,755 person-years of follow-up, 1608 new cases of T2D were documented. We used a Cox regression model to evaluate the association of fruit and vegetable intake (g/d) with the risk of T2D. Quintiles of vegetable intake and T2D were inversely associated. The relative risk for T2D for the upper quintile relative to the lower quintile of vegetable intake was 0.72 (95%CI: 0.61–0.85; $P < 0.01$) in multivariate analysis. Individual vegetable groups were all inversely and significantly associated with the risk of T2D. Fruit intake was not associated with the incidence of diabetes in this population. Our data suggest that vegetable consumption may protect against the development of T2D. J. Nutr. 138: 574–580, 2008.

Introduction

Fruits and vegetables may play a protective role in the development of type 2 diabetes (T2D),[6] as they are rich in nutrients and other components that are believed to be protective against diabetes, such as antioxidants (1) and fiber (2). Fruits and vegetables also contain numerous other beneficial phytochemicals, many of which are not documented in nutrient databases.

Data regarding the associations between fruit and vegetable intake and the risk of T2D are limited and inconsistent (3) and some studies were not properly adjusted for potential confounders (4–6). This is a problem because fruit and vegetable consumption may act as a marker for a healthy lifestyle. To our knowledge, only 3 studies have evaluated associations between specific subgroups of vegetables and hemoglobin A1c (HbA1c) and T2D incidence (3,7,8).

Asian populations traditionally have a lower risk of T2D and obesity than Western populations. However, that appears to be changing. The prevalence of both obesity and T2D have been increasing in Asian populations in recent years (9). In the baseline survey of the Shanghai Women's Health Study (SWHS) (10) conducted between 1997 and 2000, we found that the prevalence of T2D was 5.7%, the prevalence of BMI $\geq$ 23 kg/m^2 was 59.1%, and that of BMI $\geq$ 25kg/m^2 was 35.2% (our unpublished data). Change in dietary patterns is also taking place in China, including increased meat intake and decreased vegetable intake (11). Higher vegetable intake has been associated with less weight gain (12,13), a strong predictor for T2D, in Western populations. However, the association of vegetable intake with T2D risk in Chinese populations has not been well studied (14).

We evaluated the association of fruit and vegetable intake levels with the incidence of T2D in a large, population-based prospective study of middle-aged women conducted in Shanghai, China, where consumption of vegetables, especially leafy green vegetables, is high. We explored whether specific subgroups of vegetables differentially affect T2D risk and we evaluated the potential interactions of fruit and vegetable intake with obesity and physical activity categories.

Methods

Study population. The SWHS is a population-based prospective cohort study of middle-aged women (40–70 y old) conducted in 7 urban communities in Shanghai, China. Details of the SWHS survey have been reported elsewhere (10). From a total of 81,170 women who were invited to participate, 75,221 were recruited (92.7% participation rate). Reasons for nonparticipation were refusal (3.0%), absence during the enrollment period (2.6%), and other reasons such as health, hearing, and speaking problems (1.6%). After excluding women <40 y or >70 y at the time of interview ($n = 278$), 74,942 women remained for the study. Participants completed a detailed survey, including a personal interview for assessment of dietary intake, physical activity, and measurement of anthropometrics and other lifestyle factors. Protocols for the SWHS were approved by the Institutional Review Boards of all institutes involved in the study and all participants provided written, informed consent. A biannual, personal follow-up for all living cohort members was conducted via in-home visits from 2000 to 2002 and from 2002 to 2004, with a response rate of 99.8

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[6] Abbreviations used: HbA1c, hemoglobin A1c; MET, metabolic equivalent; RR, risk ratio; SWHS, Shanghai Women's Health Study; T2D, type 2 diabetes; WHR, waist-to-hip ratio.
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and 98.7%, respectively; only 934 participants were lost to follow-up. A total of 64,227 participants were free of T2D and other chronic diseases (cancer and cardiovascular disease) at baseline and they form the basis of this report.

Fruit and vegetable intake. Usual dietary intake was assessed through a personal interview using a validated FFQ at the baseline recruitment survey and again at the first follow-up survey (15). If women had a history of T2D, cancer, or cardiovascular disease reported between the baseline and follow-up surveys, we used dietary data from the baseline FFQ in the analysis. For other participants, we used the mean of the baseline and follow-up FFQ data. The means of the daily intake of individual food items (g/d) were summed to compute total fruit and vegetable intake. Soy beans, dried beans, and other legumes were not included as vegetables and were evaluated in a separate report. We created specific vegetable groups, including cruciferous vegetables, green leafy vegetables, yellow vegetables, tomatoes, allium vegetables, and other vegetables and fruit groups, including citrus, watermelon, and other fruits. (see **Appendix**). We used the Chinese Food Composition Tables (16) to estimate energy intake (kJ/d) and nutrient intakes. Of 64,227 participants who were free of T2D and other chronic diseases at baseline, we excluded participants who had extreme values for total energy intake (<2090 or >14,630 kJ/d; $n = 36$) (17), which left 64,191 participants for the final analysis.

Other factors as potential confounders. All anthropometric measurements, including weight, height, and circumferences of waist and hips, were taken at baseline recruitment according to a standard protocol by trained interviewers who were retired medical professionals (18). From these measurements, the following variables were created: BMI, weight in kilograms divided by the square of height in meters and waist-to-hip ratio (WHR), waist circumference divided by hip circumference.

A detailed assessment of physical activity was conducted using a validated questionnaire (19). The questionnaire evaluated regular exercise and sports participation during the last 5 y, daily activity, and the daily round-trip commute to work. We calculated the metabolic equivalents (MET) for each activity using a compendium of physical activity values (20). One MET (h/d) is roughly equivalent to 4.18 $kJ \cdot kg^{-1} \cdot d^{-1}$ or ~15 min of moderate intensity (4 MET) activity for an average adult (20). We combined each of the exercise and lifestyle activity indices to derive a quantitative estimate of overall nonoccupational activity (MET-h/d). Occupation-related physical activity was not related to T2D in this population and thus was not included in the current analysis.

Information on sociodemographic factors such as age, level of education (none, elementary school, middle/high school, college), family income in yuan/y (<10,000, 10,000–19,999, 20,000–29,999, ≥30,000), occupation (professional, clerical, manual worker/other, housewife/retired), smoking (smoked at least 1 cigarette per day for >6 mo continuously), and alcohol consumption (ever drank beer, wine, or spirits at least 3 times per week), and presence of hypertension at baseline was collected by using a structured questionnaire.

Outcome ascertainment. Incident T2D was identified through the follow-up surveys by asking study participants whether they had been diagnosed by a physician as having diabetes since the baseline recruitment and asking about their glucose test history and/or use of hypoglycemic medication. A total of 1608 study participants reported having a T2D diagnosis since the baseline survey. We considered a case of T2D as confirmed if a participant reported having been diagnosed with T2D and met at least 1 of the following criteria as recommended by the American Diabetes Association (21): fasting glucose level ≥7 mmol/L on at least 2 separate occasions; an oral glucose tolerance test with a value ≥11.1 mmol/L; and/or use of hypoglycemic medication (i.e. insulin or oral hypoglycemic drugs). Of the 1608 self-reported cases, a total of 896 participants met the study outcome criteria and are referred to herein as confirmed cases of T2D. We performed analyses with both confirmed and probable T2D cases and found similar results.

Statistical analysis. Person-years of follow-up for each participant were calculated as the interval between the baseline recruitment to the diagnosis of T2D censored at death or completion of the second follow-up survey. The Cox proportional hazards model was used to assess the association of fruit and vegetable intake with the incidence of T2D. Food groups (g/d) were categorized by quintile distribution, with the lowest quintile serving as the reference. Tests for trend were performed by entering the categorical variables as continuous parameters in the models. Sociodemographic factors and T2D risk factors were adjusted for in the analyses as potential confounders. In all models, we adjusted for the following potential confounding variables: age, BMI, WHR, total energy, meat intake (all entered as continuous variables), as well as income level, education level, occupation, physical activity, smoking status, alcohol consumption status, and presence of hypertension at baseline (as categorical variables).

We conducted analyses stratified by BMI, WHR, and physical activity categories. The log-likelihood ratio test was used to evaluate multiplicative interactions between fruit and vegetable intake and categories of BMI, WHR, and physical activity.

We also conducted analyses adjusting for antioxidants (vitamin C, carotene, and vitamin E) and fiber. To reduce measurement error and to adjust for extraneous variation due to total energy intake, we adjusted these nutrients by total energy intake using the residual method described by Willett and Stampfer (22).

All analyses were performed using SAS (version 9.1) and all tests of statistical significance were based on 2-sided probability.

Results

The median intake of fruits was 239.4 g/d and 236.0 g/d for vegetables. Age-standardized characteristics of the study population by fruit and vegetable intake are shown in **Table 1**. A higher intake of fruit was associated with younger age, higher physical activity, higher educational achievement, being employed, and higher household income. Participants with a higher fruit intake were more likely to have high BMI and less likely to be smokers. A higher vegetable intake was associated with younger age, higher physical activity, higher BMI, higher WHR, presence of hypertension, and nonsmoking status. Of the participants in the highest quintile of vegetable intake who were free of chronic disease at baseline, the percentage with a BMI ≥ 23 kg/m^2 was 56.7%, a BMI ≥ 25 kg/m^2 was 32.64%, and BMI ≥ 27.5 kg/m^2 was 13.10%.

During 4.6 y of follow-up (297,755 person-years total), 1608 incident cases of T2D were documented. Vegetable intake was associated with a decreased risk of T2D. Compared with the lowest quintile of intake, the multivariate adjusted relative risks (RR) of T2D across quintiles of vegetable intake were 1.00, 0.74, 0.68, 0.72, and 0.72 (P-trend < 0.001) (**Table 2**). Because participants with hypertension might have increased their fruit and vegetable intake following their diagnoses, we conducted analyses stratified by hypertension status (yes/no) and found similar results. The RR for quintiles of total vegetable intake for hypertensive participants were 1.00, 0.81, 0.65, 0.72, and 0.75 ($P < 0.001$) and 1.00, 0.70, 0.71, 0.72, and 0.70 ($P < 0.001$) for nonhypertensive participants. We also examined the association between deciles of vegetable intake and the incidence of T2D. The RR for deciles of vegetable intake were 1.00, 0.87, 0.68, 0.72, 0.61, 0.66, 0.67, 0.68, 0.64, and 0.71 ($P < 0.001$).

There were inverse associations across quintiles of intake of cruciferous vegetables, green leafy vegetables, yellow vegetables, allium vegetables, tomatoes, and other vegetables. Although trend tests were significant, some of these inverse associations did not follow a linear dose-response relationship. We did not find an association between fruit intake and the risk of T2D in this population. Compared with the lowest quintile of intake, the multivariate adjusted RR of T2D across quintiles of fruit were 1.00, 0.76, 0.79, 0.87, and 1.05 (P-trend 0.30). Similarly, we did not find a significant association between individual fruit groups and the risk of T2D. The RR associated with quintiles of consumption

TABLE 1 Age standardized characteristics of participants of the SWHS stratified by fruit and vegetable intake[1]

	Fruit quintiles					Vegetable quintiles				
	Q1	Q2	Q3	Q4	Q5	Q1	Q2	Q3	Q4	Q5
n	12,840	12,842	12,820	12,853	12,836	12,838	12,839	12,833	12,843	12,838
Age, *y*	53.9	51.7	50.6	49.9	48.8	53.0	51.1	50.5	50.3	50.0
Dietary factors										
Energy, *kJ/d*	6301.8	6650.8	6886.1	7100.6	7605.9	6069.8	6556.3	6891.6	7220.1	7832.5
Vitamin C, *mg/d*	56.7	72.5	85.6	100.5	133.9	47.3	67.5	83.6	103.2	147.7
Vitamin E, *mg/d*	10.4	12.2	13.4	14.6	17.1	9.5	11.7	13.2	15.0	18.3
Carotene, *μg/d*	1921.4	2406.2	2812.4	3255.7	4166.7	1568.8	2232.5	2736.3	3340.5	4684.1
Fiber, *g/d*	7.8	9.4	10.6	11.9	14.5	7.5	9.2	10.5	11.9	15.1
Meat intake,[2] *g/d*	55.5	62.1	65.4	67.8	73.0	52.5	60.4	64.8	69.9	76.2
WHR ≥ 0.85, *%*	20.3	19.4	18.7	18.6	20.2	19.7	19.3	18.6	19.4	19.7
BMI, *%*	23.4	23.6	23.8	23.9	24.2	23.6	23.6	23.8	23.8	24.1
≥23	54.6	54.7	56.5	57.5	61.4	52.2	54.7	56.3	58.1	62.3
≥25	32.0	30.4	32.1	32.1	36.5	29.9	30.7	32.5	33.2	36.8
≥27.5	13.7	12.5	12.6	12.6	14.8	11.7	12.1	13.0	13.3	15.5
Smoking, *%*	3.9	2.0	1.6	1.2	1.7	2.9	2.3	1.8	1.8	2.0
Alcohol, *%*	2.7	2.2	2.0	1.9	2.5	2.3	2.1	2.1	2.3	2.5
Exercise, *%*	25.3	31.0	34.5	36.5	38.0	26.4	30.1	32.9	36.2	39.5
High PA,[3] *%*	23.9	23.5	24.1	25.0	29.1	21.8	22.8	24.6	26.4	29.4
Education, *%*										
None	21.7	19.1	17.8	16.5	15.6	24.6	18.5	15.9	15.0	14.9
Elementary	40.1	39.2	38.9	38.1	38.4	42.5	40.1	39.0	37.1	37.6
Up to high school	26.3	18.1	29.6	30.7	30.6	23.6	27.4	29.6	31.9	32.6
College	11.9	13.6	13.8	14.7	15.3	9.3	13.9	25.4	16.0	14.9
Income level, *%*										
<10,000 yuan/y	21.6	15.4	13.7	13.1	13.3	15.7	15.1	14.9	14.8	16.6
10,000–19,999 yuan/y	41.8	40.0	37.8	36.7	34.8	37.8	38.1	37.9	38.7	37.7
20,000–29,999 yuan/y	24.3	28.4	30.3	30.0	29.6	29.4	28.9	28.9	28.5	27.3
≥30,000 yuan/y	12.3	16.2	18.2	20.2	22.3	17.1	17.9	18.3	18.0	18.4
Occupation, *%*										
Professional	14.9	19.4	21.4	22.0	21.0	19.1	20.4	20.1	20.6	19.3
Clerical	13.4	13.4	12.9	12.8	12.6	12.6	13.1	12.9	12.8	13.5
Manual worker/other	22.9	23.2	23.0	22.7	12.7	23.1	22.9	23.9	23.1	21.8
Housewife/retired	48.1	43.9	42.6	42.5	43.8	45.2	43.6	43.1	43.5	45.4
Hypertension, *%*	18.5	18.2	19.4	18.7	19.4	16.8	18.5	19.1	19.6	20.2

[1] Values are means or percentages.
[2] Meat intake is a composite variable that includes beef, poultry, pork, and organ meat.
[3] High PA: Upper quartile of the MET distribution of total nonoccupational physical activity.

of citrus fruits were 1.00, 0.84, 0.84, 0.81, and 1.11 ($P = 0.36$), 1.00, 0.84, 0.83, 0.90, and 1.04 ($P = 0.47$) for watermelon, and 1.00, 0.77, 0.68, 0.85, and 0.90 ($P = 0.28$) for other fruits.

In analyses restricted to confirmed diabetes cases, we found similar results (**Table 3**). We excluded participants who had been diagnosed with T2D during the first year of follow-up. The adjusted RR for T2D across quintiles relative to the lowest quintile were 1.00, 0.76, 0.68, 0.69, and 0.68 ($P < 0.001$) for vegetables and 1.00, 0.81, 0.83, 0.88, and 1.08 ($P = 0.31$) for fruit.

We assessed potential effect modification by BMI (<25 or ≥25) and WHR (<0.85 and >0.85) and physical activity levels (using the lower 25% quartile as the cut-off point of the MET distribution) with fruit and vegetable intake (**Table 4**). BMI, WHR, or physical activity did not modify the association between fruit and vegetable intake and T2D.

We further explored whether the effect of fruit and vegetables in the development of T2D could be explained by antioxidants, fiber, and magnesium. We added each nutrient in the model one at a time and in combination to examine whether the primary association with fruit or vegetable intake could be explained by nutrient intake. The inverse association between vegetable intake and T2D became slightly accentuated when the model included vitamin C, carotene, and fiber, or all antioxidants, magnesium, and fiber together. The RR of T2D across quintiles of vegetable intake were 1.00, 0.71, 0.63, 0.63, and 0.56 (*P*-trend <0.001) in the analysis adjusted for fiber, magnesium, and all antioxidants. We observed a modest increase in risk of T2D in participants in the highest quintile of fruit intake after adjustment for vitamin C, carotene, fiber, and magnesium, and all antioxidants, magnesium, and fiber together. The RR for the highest quintile compared with the lowest quintile for T2D in fully adjusted analysis was 1.21 (95%CI: 0.99–1.49). It is noteworthy that some of the nutrients were highly correlated with vegetable and fruit intake. Colinearity may have limited our ability to sort out the factors responsible for the vegetable and diabetes association.

Discussion

In this large, prospective, population-based study of middle-aged Chinese women, higher intake of vegetables was associated

TABLE 2 Hazard ratio (HR) of T2D by quintiles of food groups in the SWHS[1]

	Q1	Q2	Q3	Q4	Q5	*P*-trend[2]
All vegetables, *g/d*	121.5	181.6	236.0	302.6	428.0	
Cases, *n*	415	296	270	299	325	
Person-years	59,311	59,858	59,904	59,524	9146	
HR (95%CI)	1.00	0.74 0.64–0.87	0.68 0.58–0.80	0.72 0.61–0.84	0.72 0.61–0.85	<0.001
Cruciferous vegetables, *g/d*	5.0	10.9	17.0	25.8	45.2	
Cases, *n*	421	318	282	250	334	
Person-years	59,258	59,744	59,573	59,738	59,431	
HR (95%CI)	1.00	0.79 0.68–0.91	0.69 0.60–0.81	0.60 0.51–0.71	0.72 0.61–0.83	<0.001
Green/leafy vegetables, *g/d*	28.0	51.3	70.7	94.1	136.1	
Cases, *n*	408	320	252	247	378	
Person-years	59,409	59,820	59,784	59,867	58,864	
HR (95%CI)	1.00	0.78 0.68–0.91	0.61 0.52–0.71	0.58 0.49–0.68	0.82 0.71–0.95	<0.001
Yellow vegetables, *g/d*	0.04	0.62	2.00	5.6	17.3	
Cases, *n*	443	327	290	248	297	
Person-years	58,898	59,419	59,835	59,552	59,174	
HR (95%CI)	1.00	0.69 0.60–0.80	0.63 0.54–0.73	0.51 0.43–0.60	0.55 0.47–0.64	<0.001
Allium vegetables, *g/d*	2.2	4.2	6.5	9.8	17.9	
Cases, *n*	393	309	286	293	324	
Person-years	59,540	59,644	59,835	59,552	59,174	
HR (95%CI)	1.00	0.79 0.68–0.92	0.70 0.60–0.81	0.70 0.60–0.82	0.69 0.59–0.81	<0.001
Tomatoes, *g/d*	6.8	17.0	30.3	49.2	88.5	
Cases, *n*	469	285	298	244	309	
Person-years	59,080	59,663	59,648	59,702	59,651	
HR (95%CI)	1.00	0.68 0.59–0.79	0.73 0.63–0.85	0.61 0.52–0.71	0.78 0.67–0.91	<0.001
Other vegetables, *g/d*	40.7	66.8	90.9	121.4	181.0	
Cases, *n*	398	285	317	286	319	
Person-years	59,106	60,016	59,656	59,849	59,117	
HR (95%CI)	1.00	0.76 0.65–0.88	0.84 0.72–0.98	0.76 0.64–0.89	0.76 0.64–0.89	<0.01
All fruits, *g/d*	87.0	170.4	239.4	315.0	4	
Cases, *n*	421	271	270	288	355	
Person-years	58,846	59,708	59,733	59,905	59,555	
HR (95%CI)	1.00	0.76 0.65–0.88	0.79 0.67–0.92	0.87 0.74–1.02	1.05 0.90–1.23	0.30
Citrus fruit, *g/d*	2.5	10.0	16.7	25.2	44.4	
Cases, *n*	402	292	278	262	371	
Person-years	58,437	59,594	60,438	59,389	59,886	
HR (95%CI)	1.00	0.84 0.72–0.98	0.84 0.72–0.98	0.81 0.69–0.95	1.11 0.95–1.29	0.36
Watermelon, *g/d*	29.6	71.3	109.7	149.1	221.0	
Cases, *n*	390	295	280	294	346	
Person-years	58,907	59,953	59,815	59,646	59,424	
HR (95%CI)	1.00	0.84 0.72–0.98	0.83 0.71–0.97	0.90 0.77–1.05	1.04 0.89–1.21	0.47
Other fruit, *g/d*	27.6	67.2	102.2	142.7	217.6	
Cases, *n*	444	288	254	298	346	
Person-years	58,796	59,636	59,743	59,721	59,846	
HR (95%CI)	1.00	0.77 0.66–0.90	0.68 0.58–0.80	0.85 0.73–0.99	0.90 0.77–1.05	0.28

[1] Intakes are medians.

[2] The Cox proportional hazards model was used to assess the effect of food group or soy protein consumption on the incidence of type 2 DM. RR: Adjusted for age, daily energy intake, meat intake, BMI, WHR, smoking, alcohol consumption, physical activity, income level, education level, occupational status, and hypertension. Tests for trend were performed by entering the categorical variables as continuous variables in the models.

with a reduced risk of T2D. Fruit intake and T2D risk were not associated.

Our study adds to the limited and conflicting data available on fruit and vegetable intake and the risk of T2D. An inverse association between vegetable, but not fruit, intake and glucose intolerance has been found in cross-sectional (6) and prospective studies (3,4,23) similar to our study. Inverse associations between both fruit and vegetable intake and the risk of glucose intolerance (5,8,24) and HbA1c (7) have been also been reported. However, other studies have found no association between fruit and/or vegetable intake and T2D risk (5,14,25–27) or levels of HBA1c (28). In a randomized control trial among 577 participants with impaired glucose tolerance conducted in China, a diet high in fruits and vegetables appeared to reduce the incidence of T2D by 24% (29). A diet high in fruit and vegetables was also associated with a higher insulin sensitivity in the Dietary Approaches to Stop Hypertension intervention trial (30).

Few studies have looked at individual vegetable groups and the risk of T2D. Yellow and dark-green vegetable intake has been associated with lower HbA1c levels and T2D incidence

TABLE 3 HR of T2D by quintiles of food groups in analyses restricted to confirmed cases of diabetes in the SWHS[1,2]

	Q1	Q2	Q3	Q4	Q5	*P*-trend[3]
All vegetables, *g/d*	1.00	0.71 0.58–0.87	0.66 0.54–0.81	0.69 0.56–0.85	0.65 0.52–0.81	<0.001
Cruciferous vegetables, *g/d*	1.00	0.83 0.68–1.01	0.75 0.61–0.92	0.69 0.56–0.85	0.70 0.56–0.86	<0.01
Green leafy vegetables, *g/d*	1.00	0.86 0.70–1.04	0.69 0.56–0.85	0.67 0.54–0.82	0.78 0.64–0.96	<0.01
Yellow vegetables, *g/d*	1.00	0.71 0.59–0.88	0.63 0.51–0.77	0.49 0.39–0.61	0.58 0.47–0.71	<0.001
Allium vegetables, *g/d*	1.00	0.89 0.73–1.09	0.65 0.52–0.81	0.85 0.69–1.04	0.84 0.68–1.03	0.09
Tomatoes, *g/d*	1.00	0.76 0.62–0.93	0.82 0.67–1.00	0.68 0.55–0.84	0.82 0.66–1.01	0.02
Other vegetables, *g/d*	1.00	0.74 0.60–0.90	0.75 0.61–0.93	0.75 0.60–0.85	0.68 0.54–0.85	<0.01
All fruits, *g/d*	1.00	0.71 0.58–0.88	0.73 0.59–0.90	0.86 0.70–1.05	0.94 0.76–1.16	0.94

[1] The Cox proportional hazards model was used to assess the effect of food group or soy protein consumption on the incidence of type 2 DM. RR: Adjusted for age, daily energy intake, meat intake, BMI, WHR, smoking, alcohol consumption, physical activity, income level, education level, occupational status, and hypertension.
[2] Values are HR (95%CI).
[3] Tests for trend were performed by entering the categorical variables as continuous variables in the models.

(3,7). In a middle-aged Finnish population, green vegetables but not yellow/red vegetables were associated with a lower incidence of T2D (8). In the Women's Health Study, BMI appeared to be an effect modifier on the association between green or dark-yellow vegetable intake and T2D (3). In our study, both green and yellow vegetable intakes were inversely associated with T2D. We found that neither BMI nor WHR modified the effect of vegetable intake on risk of T2D.

Several studies investigating the association between fruit and vegetable intake were based on cross-sectional surveys and adjusted for a limited number of confounders. For example, in the Seven Countries study, an inverse relationship between vegetable intake and 2-h glucose concentration in an oral glucose tolerance test was found, but the analyses were adjusted for only cohort, age, BMI, and energy intake (4). In a cross-sectional study of a Canadian native population, a protective effect of vegetables on impaired glucose tolerance or T2D was reported (OR = 0.41; 95%CI: 0.18–0.91) (5). This analysis, however, was adjusted for only age and sex. Another cross-sectional study in the UK found a decreased risk of T2D associated with salad and raw vegetable consumption (OR = 0.16; 95%CI: 0.04–0.81) with adjustment for age, sex, and family history of T2D (6). When BMI was adjusted for, the association was attenuated. None of these studies adjusted for smoking habits, physical activity, or meat intake.

TABLE 4 HR of T2D by fruit and vegetable intake stratified by BMI, WHR, and physical activity in the SWHS[1]

	Q1	Q2	Q3	Q4	Q5	*P*–trend[2]
All vegetables						
BMI <25[3]	1.00	0.59 0.45–0.76	0.64 0.49–0.83	0.69 0.53–0.90	0.68 0.51–0.90	<0.001
BMI ≥25	1.00	0.85 0.71–1.02	0.71 0.59–0.87	0.77 0.63–0.94	0.79 0.64–0.96	0.01
P interaction = 0.20						
WHR <0.85[4]	1.00	0.77 0.62–0.94	0.62 0.50–0.77	0.69 0.56–0.85	0.69 0.56–0.87	<0.001
WHR ≥0.85	1.00	0.70 0.56–0.88	0.74 0.58–0.93	0.74 0.58–0.93	0.72 0.57–0.92	<0.01
P interaction = 0.10						
Low PA[5]	1.00	0.74 0.56–0.99	0.56 0.40–0.76	0.75 0.56–1.00	0.60 0.43–0.84	<0.01
Medium/high PA	1.00	0.75 0.62–0.89	0.72 0.60–0.86	0.70 0.58–0.84	0.75 0.62–0.91	<0.01
P interaction = 0.34						
Fruits						
BMI <25[3]	1.00	0.76 0.58–0.99	0.89 0.68–1.17	0.99 0.76–1.30	1.18 0.90–1.55	0.08
BMI ≥25	1.00	0.72 0.60–0.87	0.72 0.59–0.87	0.79 0.65–0.96	0.98 0.81–1.18	0.97
P interaction = 0.7						
WHR <0.85[4]	1.00	0.65 0.53–0.81	0.69 0.55–0.85	0.71 0.58–0.89	0.94 0.77–1.16	0.80
WHR ≥0.85	1.00	0.85 0.67–1.06	0.89 0.70–1.12	1.06 0.84–1.33	1.12 0.89–1.42	0.15
P interaction = 0.05						
Low PA[5]	1.00	0.63 0.47–0.86	0.81 0.60–1.09	0.84 0.62–1.13	0.79 0.57–1.08	0.42
Medium/high PA	1.00	0.80 0.67–0.96	0.77 0.64–0.93	0.87 0.73–1.05	1.14 0.95–1.36	0.14
P interaction = 0.26						

[1] The Cox proportional hazards model was used to assess the effect of food group or soy protein consumption on the incidence of T2D.
[2] Tests for trend were performed by entering the categorical variables as continuous parameters in the models.
[3] Adjusted for age, daily energy intake, meat intake, WHR, smoking, alcohol consumption, physical activity, income level, education level, occupational status, and hypertension.
[4] Adjusted for age, daily energy intake, meat intake, BMI, smoking, alcohol consumption, physical activity, income level, education level, occupational status, and hypertension.
[5] Adjusted for age, daily energy intake, meat intake, BMI, WHR, smoking, alcohol consumption, income level, education level, occupational status, and hypertension.

The mechanism by which vegetables affect glucose tolerance has not been clearly defined but may be associated with the high content of antioxidants, (1) fiber (2), and magnesium (31) or the low glycemic index in vegetables (32). Chronic administration of vitamin E has been reported to improve insulin sensitivity (33) and vitamin C was associated with higher insulin action in both healthy and diabetic people (34). However, in the Health Professionals Follow-Up Study, there was no association with the incidence of T2D after 12 y of supplementation with β-carotene (35). In our study, the inverse association between vegetable intake and T2D persisted after adjustment for vitamin C, vitamin E, carotene, and fiber intake. Further adjustment for magnesium intake did not alter the association. Taking this evidence into consideration, it appears that the beneficial effects of vegetable consumption on the risk of T2D cannot be entirely explained by antioxidant vitamins, magnesium, or fiber intake. Vegetables also contain other compounds such as phytates, lignans, and isoflavones that might have an additive or synergistic effect on lowering the risk of T2D.

Our data suggest that fruit consumption is not associated with a lower risk of T2D in this population. Other studies have found similar results (3,6,23,27). We do not have a ready explanation as to why fruit was not associated with a lower risk of T2D in our study population. We speculate that the high fructose content of fruit may counteract the protective effect of antioxidants, fiber, and other antidiabetic compounds of fruit. It has been suggested that sugars containing fructose may play a major role in the development of hypertension, obesity, diabetes, the metabolic syndrome, and in the subsequent development of kidney disease (36). However, high serum uric acid concentrations, which have been associated with the metabolic syndrome (37), were not found to be related to fruit juice intake in a recent study using NHANES data (38). More research is needed to investigate the association between fructose in fruit and health outcomes.

Several alternative explanations should be considered when interpreting our findings. First, the exact benefit of fruit and vegetable intake is very difficult to assess when multiple factors such as exercise, not smoking, and maintaining a healthy weight may also be contributing a beneficial effect (the healthy lifestyle bias) and protecting participants from developing T2D. Fruit and vegetable consumption may act as a marker for a healthy lifestyle and healthy dietary pattern in general (6,39). This is a potential problem in many observational studies of diet and disease and it is difficult to exclude. However, in China, dietary patterns are quite different from Western societies. Vegetables are widely consumed in Shanghai and less correlated with socio-economic status. Fruit intake, on the other hand, is associated with higher socioeconomic factors in this population. Although we adjusted for education and income in the analysis, residual confounding remains a possible concern for our results, together with potential unmeasured confounders.

Participants in the SWHS are a representative sample of the Chinese, middle-aged female population in Shanghai. The prospective design, high participation rate, and high follow-up rates minimized the possibility of selection or recall bias. The repeated dietary measurements improved the quality of the dietary information and the extensive information available allowed us to adjust for a wide range of potentially confounding variables. An important limitation of our study is reliance on self-reports of T2D. Analyses restricted to participants whose diagnosis of T2D was confirmed according to our study criteria showed inverse associations between vegetable intake and the incidence of T2D. Recall of dietary intake is subject to misclassification. This kind of nondifferential misclassification would tend to weaken associations between fruit and vegetable intake and T2D. The prediagnostic or preclinical manifestations of T2D might have lead to changes in diet. After we excluded probable cases of T2D and participants diagnosed within the first year of follow-up, our analyses showed a clearer linear association of vegetable intake with T2D than analyses that included the total population. Further follow-up of the cohort would provide a more definite assessment of the vegetable and T2D association.

Our study adds to the limited and conflicting data of the associations between fruit and vegetable intake and the risk of T2D. A higher intake of vegetables, rich in fiber, antioxidants, and magnesium and with a low glycemic index, was associated with a decreased risk of T2D.

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Appendix: Composition of food groups shown in Table 2

Food groups	Food items
Cruciferous vegetables	Green cabbage, Chinese cabbage, cauliflower, white turnip
Green leafy vegetables	Greens, Chinese greens, spinach
Yellow vegetables	Sweet potatoes, carrots
Allium vegetables	Garlic, garlic shoots, heads of garlic, onions, green onions, Chinese chives
Tomatoes	Tomatoes
Other vegetables	Soy bean sprouts, mug bean sprouts, black and white tree fungi, dried xiangu mushrooms, celery, eggplant, wild rice stems, asparagus lettuce, wax gourd, cucumbers, lufa, fresh mushrooms, peppers, bamboo shoots, lotus root
Fruits	Apples, pears, citrus (tangerines, oranges, grapefruit), banana, grapes, watermelon, peaches, other (strawberries, cantaloupe)