Long-term Diet Quality and Risk of Type 2 Diabetes Among Urban Chinese Adults

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OBJECTIVE

Little evidence exists regarding long-term diet quality and the risk of type 2 diabetes among Asian populations, who have undergone a nutrition transition and a diabetes epidemic.

RESEARCH DESIGN AND METHODS

A total of 117,919 Chinese men and women, 40–74 years old, free of diabetes, cardiovascular disease, and cancer at baseline, were followed from 1996 to 2015. Diet quality was assessed by a healthy diet score (HDS) based on eight commonly consumed food groups previously suggested to be related to diabetes. Long-term diet quality and its changes were assessed by repeated surveys using food-frequency questionnaires.

RESULTS

We identified 6,111 incident diabetes cases during a mean follow-up of 11.5 years. Higher HDS was associated with lower diabetes risk (hazard ratio [HR] 0.85 [95% CI 0.78–0.92] in the highest vs. lowest quintile, $P_{\text{continuous}}$ <0.0001) after adjustment for potential confounders including BMI. Maintaining a high HDS during follow-up was associated with 26% lower risk compared with a consistently low HDS (HR 0.74 [95% CI 0.63–0.85]). The inverse association between HDS and diabetes was observed regardless of participants' age, sex, smoking and exercise habits, obesity status, and metabolic disease status but was more prominent among those who participated in leisure-time exercise ($P_{\text{interaction}}$ = 0.004). When considered jointly, a sustained high HDS plus exercise was associated with a 45% reduced risk of diabetes (HR 0.55 [95% CI 0.45–0.67]).

CONCLUSIONS

A high-quality diet, especially maintained over the long term and in conjunction with leisure-time exercise, is associated with lower risk of type 2 diabetes among urban Chinese adults.

Type 2 diabetes is an emergent global health crisis; 9% of the world's adult population is living with diabetes, and 14.5% of all-cause mortality among people in the age range of 20 to 79 years is attributable to diabetes (1). Besides health burden, diabetes also imposes a huge economic burden; 12% of health expenditure worldwide is spent on treatments for diabetes and its complications, making it one of the most expensive diseases (1,2). China, India, and the U.S. are leading the global diabetes epidemic in terms of the number of adults with diabetes and the health care spending on diabetes (1). Preventing diabetes has become undoubtedly a top public health priority in these nations and worldwide.

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Evidence from prospective cohort studies and randomized controlled trials has converged to support the important role of healthy eating in the prevention of type 2 diabetes (3,4). Individuals with an overall healthy diet, such as the Mediterranean-style diet; the Dietary Approaches to Stop Hypertension (DASH) diet, a healthy plant-based diet; and a diet following the *Dietary Guidelines for Americans* were found to have an ~25% lower risk of the development of diabetes (3,5–7). Meanwhile, large long-term trials have shown that lifestyle interventions (diet alone or diet plus exercise) can reduce diabetes risk by 35% on average, appeared to be more effective than treatment with metformin, and may sustain beneficial effects for years after the active intervention stopped (4).

However, although much has been learned about the impact of healthy eating on diabetes prevention, most studies have been conducted among Western populations living in developed countries (mostly white adults in the U.S. and Europe). Those findings may not be directly generalizable to populations with different dietary habits and possibly different diabetes pathophysiology (3,5,8). Moreover, most studies have used only a single measure of diet at baseline, which may not capture long-term diet and its changes. Evidence remains scarce regarding long-term dietary pattern/quality in relation to the risk of type 2 diabetes, particularly among Asian populations who traditionally consume a plant-based diet but have undergone the nutrition transition toward a Western-style diet.

Therefore, we conducted a prospective analysis to evaluate overall diet quality and changes in diet quality in association with the risk of type 2 diabetes during 1996 and 2015 using resources of the Shanghai Women's Health Study (SWHS) and the Shanghai Men's Health Study (SMHS). Diet quality was assessed by a priori food group–based healthy diet score. Long-term diet quality and its changes were captured using data from repeated dietary surveys during cohort follow-up.

RESEARCH DESIGN AND METHODS

Study Population

The SWHS and SMHS are two population-based, prospective cohort studies that recruited 74,940 women and 61,480 men, 40–74 years old, from Shanghai, People's Republic of China, during 1996–2000 and 2002–2006, respectively. Detailed study design and methods were published previously (9,10). Briefly, in-person interviews were conducted at baseline using structured questionnaires to collect information on sociodemographics, diet, lifestyle, and medical history; anthropometrics were also measured by trained study staff. Both cohorts have been followed up for death and chronic disease outcomes via linkages to the Shanghai Vital Statistics and Cancer Registries annually (completion rates >99%), as well as home visits every 2–4 years (response rates >90%). Diet, lifestyle, and anthropometrics information has been updated during home visits. The SWHS and SMHS were approved by the Institutional Review Boards of the Shanghai Cancer Institute and Vanderbilt University. All participants provided informed consent.

In the present analysis, we excluded participants who reported a history of diabetes, cardiovascular disease, or cancer or an extreme total energy intake (<500 or >3,500 kcal/day for women, <800 or >4,200 kcal/day for men) at baseline. A total of 64,802 women and 53,117 men were included.

Diet Assessment

Usual dietary intakes were assessed using validated, semiquantitative food-frequency questionnaires (FFQs). During 1996–2011, three FFQs were implemented in the SWHS with 95% of eligible participants completing at least two FFQs and 83% completing all three FFQs. During 2002–2011, two FFQs were implemented in the SMHS with 80% of eligible participants completing both FFQs. Participants were asked generally about the frequency (daily, weekly, monthly, yearly, or never) and amount (in *liang* [50 g]) of their consumption of each food or food group in the past 12 months. The FFQs were validated against multiple 24-h dietary recalls that were administered twice a month in the SWHS and once a month in the SMHS consecutively for 12 months among randomly selected cohort participants (11,12). Both FFQs show reasonably high validity and reproducibility. Correlation coefficients for major food groups including vegetables, fruits, legumes, fish, red meat, and refined grains were 0.41–0.66 in the SWHS and 0.42–0.72 in the SMHS.

A healthy diet score (HDS) was calculated based on eight food groups (i.e., vegetables [excluding potatoes], fruits, dairy products, fish and seafood, nuts and legumes, red meat, processed meat, and refined grains). These food groups were commonly consumed by our study participants, and results from recent meta-analyses of cohort studies (13–18) largely supported their associations with diabetes risk. In the SWHS and SMHS separately, food intakes were adjusted for total energy intake using the residual method and divided into quintiles (except for processed meat, for which we assessed only consumption frequency, which was divided into five groups: none or less than once every 2 months, less than once per month, less than twice per month, less than once per week, or greater than or equal to once per week). Based on these quintiles, the first five food groups were assigned ascending values (1–5) and the last three groups were assigned descending values (5–1); their sum presented the HDS (8–40, the higher the score, the healthier the diet). Using data from repeated FFQs, we calculated the cumulative averages of the HDS and food intakes during follow-up, as well as changes in the HDS between adjacent FFQ assessments. If heart disease, stroke, or cancer developed in participants during follow-up, we stopped updating their dietary data and censored their follow-up to avoid the potential influence of diet changes and treatments after these disease diagnoses on our results.

Diabetes Assessment

Diabetes information was asked at baseline and at each follow-up visit. Diabetes was confirmed if participants reported having received a diagnosis of type 2 diabetes from a physician and also met at least one of the following criteria: *1*) fasting glucose concentration of ≥7.0 mmol/L (126 mg/dL) on at least two occasions; *2*) 2-h postprandial glucose concentration of ≥11.1 mmol/L (200 mg/dL) on at least two occasions; *3*) use of antidiabetes medication; and *4*) the presence of any diabetes symptoms (frequent urination, increased thirst, increased hunger, and unexplained weight loss) plus fasting glucose concentration of ≥7.0 mmol/L (126 mg/dL) or 2-h postprandial glucose of ≥11.1 mmol/L (200 mg/dL). Participants who reported a possible diabetes diagnosis but did not meet other criteria were not considered to be case patients in our main analysis.

Statistical Analysis

Baseline characteristics of study participants across quintiles of the HDS were compared by using general linear regression for continuous variables and the χ^2 test for categorical variables. The Cox proportional hazards model was used to assess the hazard ratio (HR) and 95% CI with age as the time scale. Dietary exposures were modeled as time-varying variables and related to events that occurred in the subsequent follow-up period. Time in the study was counted from the date of FFQ assessment to the date of diagnosis with diabetes, heart disease, stroke, or cancer or death, loss to follow-up, or end of follow-up (10 June 2015 for both cohorts), whichever came first. In consideration of the different enrollment times of the two cohorts and the possible sex-specific effects of diet on diabetes, analyses were conducted separately in men and women, and results were pooled using fixed-effect meta-analysis given that we did not observe significant heterogeneity between sexes.

The Cox model was stratified by follow-up periods and adjusted for total energy intake (kcal/day), education (elementary school or less, middle school, high school, or professional or college education or higher), income (in women, household income $<$10,000, 10,000–19,999, 20,000–29,999, or $\geq$30,000 yuan/year; in men, personal income $<$6000, 6000–11,999, 12,000–23,999, or $\geq$24,000 yuan/year), smoking status (in women, never or ever; in men, never, past, or current $<$12 or $\geq$12 cigarettes/day), alcohol drinking (in women, never or ever; in men, never, past, or current $<$2 or $\geq$2 drinks/day [1 drink = 14 g ethanol]), leisure-time exercise (none, less than, or greater than median exercise time [hours/week], assessed using validated questionnaires) (19,20), family history of diabetes (yes/no), history of hypertension (yes/no), history of dyslipidemia (yes/no), and, in women, postmenopausal status (yes/no). In the final model, we also adjusted for BMI (in kilograms per meters squared) and evaluated to what extent the HDS-diabetes association may be explained by BMI as an intermediate variable (mediation analyses comparing models with and without adjustment for BMI using the SAS (SAS Institute, Cary, NC) macro %mediate (21). Updated information on smoking, alcohol drinking, exercise, disease status, menopausal status, and BMI was used when available and modeled as time-varying covariates.

We further examined HDS changes in relation to diabetes risk. Participants were classified into the following five groups: the low-low or high-high group included those who stayed in the lowest or highest quintile of the HDS in all FFQs; the low-high or high-low group included those whose HDS changed from 1st/2nd to 4th/5th quintiles or from 4th/5th to 1st/2nd quintiles between adjacent FFQ assessments; the medium group included those who stayed in the 2nd to 4th quintile or who had small changes in the HDS (e.g., moved one quintile).

To identify the potential effect modifiers on the diet-diabetes association, we conducted stratified analyses by age, education, smoking, exercise, BMI, family history of diabetes, and history of hypertension or dyslipidemia. The *P* value for interaction was determined by likelihood ratio test comparing models with and without interaction terms. We also performed sensitivity analyses by using the baseline or the most recent FFQ data instead of the accumulative average of HDS, by excluding early follow-up time (the first 2 years) to minimize potential influence of preclinical diet changes on the risk estimates, and by treating all instances of self-reported diabetes as cases. All statistical analyses were two-sided (α = 0.05) and were performed using SAS version 9.4 (SAS Institute).

RESULTS

At baseline, participants with higher HDSs had higher levels of education and income and were more likely to be never smokers, to have moderate alcohol consumption, and to exercise in their leisure time (Table 1). Among women, higher HDS was associated with younger age and lower prevalence of hypertension, but the opposite associations were observed among men. The average BMIs in both men and women were ~24 kg/m^2.

During mean follow-ups of 13.6 years in the SWHS and 8.8 years in the SMHS, we identified 6,111 incident diabetes case patients (3,480 women and 2,631 men). A higher HDS was associated with a lower risk of diabetes in both sexes (Table 2). Participants in the highest quintile of HDS showed a 26% lower risk than those in the lowest quintile in the age- and energy-adjusted model. Additional adjustment for potential confounders, including socioeconomic status, lifestyles, and history of hypertension and dyslipidemia, somewhat attenuated the association; the HR in the highest versus lowest quintile of HDS was 0.83 (95% CI 0.76–0.91; $P_{\text{continuous}} < 0.0001$). We further included BMI in the model and found a slight attenuation of the HDS-diabetes association in women but not in men; the estimated mediation effect of BMI among women was 21.3% (95% CI 12.1–34.9%, $P_{\text{mediation}}$ = 0.0001). Results were unchanged if the baseline waist/hip ratio was also included in the model. The HR in the final multivariable and BMI-adjusted model was 0.85 (95% CI 0.78–0.92) in the highest versus lowest quintile of HDS ($P_{\text{continuous}} < 0.0001$).

We then examined the associations of HDS changes with diabetes risk. Most participants (~85%) had no or small changes in their overall diet quality during follow-up. Participants who maintained a high HDS (the 5th quintile) throughout the follow-up showed a 26% lower risk of diabetes compared with those who had a consistently low HDS (the 1st quintile) (Table 3, the high-high vs. low-low group); the HR in the multivariable and BMI-adjusted model was 0.78 (95% CI 0.65–0.95) in women, 0.66 (95% CI 0.52–0.85) in men, and 0.74 (95% CI 0.63–0.85) when pooled. Among a small portion of participants whose HDSs improved during follow-up (the low-high group), the HR was 0.86 (95% CI 0.74–0.99) in the multivariable adjusted model but was diminished after adjustment for BMI.

We did not observe significant effect modifications in stratified analyses (Supplementary Table 1) except that the HDS-diabetes association was stronger among participants who had a higher education level ($P_{\text{interaction}}$ = 0.02) and who had leisure-time exercise ($P_{\text{interaction}}$ = 0.004). The HR in the highest versus lowest quintile of HDS was 0.89 (95% CI 0.80–0.99) among participants without exercise and 0.72 (95% CI 0.63–0.83) among participants with exercise. Among those with exercise, both the high-high and low-high HDS groups showed reduced risk of diabetes: HRs were 0.65 (95% CI 0.52–0.81) and 0.64 (95% CI 0.50–0.83), respectively, versus the low-low group.

Given the significant interaction between HDS and exercise, we further evaluated their potential joint effect (Fig. 1). A healthy diet plus leisure-time exercise was associated with a particularly reduced risk of diabetes compared with diet or exercise alone. Compared with participants who had no exercise and a low HDS, the HR was 0.62 (95% CI 0.55–0.71) for those

Table 1—Age-adjusted baseline characteristics by quintiles of the HDS in the SWHS and SMHS

	Women (*n* = 64,802, 1996–2000)			Men (*n* = 53,117, 2002–2006)		
Characteristics	Quintile 1	Quintile 3	Quintile 5	Quintile 1	Quintile 3	Quintile 5
HDS, mean ± SD	17.0 ± 1.9	24.0 ± 0.8	32.1 ± 2.0	17.1 ± 1.9	24.0 ± 0.8	31.4 ± 2.3
Age (years), mean ± SD	53.1 ± 9.2	51.3 ± 8.7	50.5 ± 8.1	53.3 ± 9.1	53.9 ± 9.0	55.4 ± 9.5
High education† (%)	7.8	13.6	20.2	11.8	21.9	34.7
High income† (%)	12.4	17.7	23.6	5.1	9.4	14.9
Tobacco smoking (%)						
Never	95.7	97.6	98.5	19.6	28.1	40.2
Ever	4.3	2.4	1.5	80.4	71.9	59.8
Past				7.4	8.8	10.9
Current <12 cigarettes/day				22.1	23.5	20.9
Current ≥12 cigarettes/day				50.9	39.7	28.0
Alcohol drinking (%)						
None	97.9	97.9	97.3	65.8	65.1	67.2
Ever	2.1	2.1	2.7	34.2	34.9	32.8
Past				4.4	3.5	3.0
Current <2 drinks/day				16.8	19.1	20.7
Current ≥2 drinks/day				13.1	12.3	9.1
Leisure-time physical activity (%)	25.7	32.7	40.9	22.8	30.8	43.9
Postmenopause (%)	50.6	43.3	41.2			
Family history of diabetes (%)	14.0	16.1	16.9	17.1	16.9	16.2
History of hypertension (%)	20.4	18.9	18.3	22.5	24.4	27.5
BMI (kg/m^2), mean ± SD	24.2 ± 3.4	23.8 ± 3.2	23.7 ± 3.5	23.6 ± 3.2	23.6 ± 3.0	23.7 ± 2.9
Dietary intake,‡ mean ± SD						
Total energy (kcal/day)	1,752 ± 405	1,682 ± 382	1,625 ± 419	2,017 ± 493	1,929 ± 460	1,848 ± 445
Fruits (g/day)	141 ± 145	255 ± 137	410 ± 150	66 ± 116	143 ± 108	250 ± 104
Vegetables (g/day)	171 ± 123	263 ± 116	405 ± 128	202 ± 145	310 ± 135	449 ± 130
Dairy products (g/day)	28 ± 246	91 ± 232	199 ± 255	30 ± 183	103 ± 171	206 ± 165
Fish (g/day)	25 ± 36	46 ± 34	80 ± 38	24 ± 40	48 ± 37	80 ± 36
Legumes and nuts (dry weight, g/day)	11 ± 11	18 ± 11	26 ± 12	14 ± 13	22 ± 12	31 ± 12
Refined grains (g/day)	359 ± 37	313 ± 35	259 ± 39	419 ± 45	371 ± 42	321 ± 41
Red meat (g/day)	54 ± 29	51 ± 27	38 ± 30	65 ± 37	65 ± 35	53 ± 33
Processed meat (times/month)	2.2 ± 2.9	1.9 ± 2.7	1.3 ± 3.0	2.0 ± 2.3	1.7 ± 2.2	1.2 ± 2.1

Continuous and categorical variables were compared by general linear regression and χ^2 tests, respectively. All $P < 0.05$ for comparison among quintiles, with exception of family history of diabetes in men. †High education was defined as having professional or college education or more. High income was defined as family income ≥30,000 yuan/year in the SWHS and personal income ≥24,000 yuan/year in the SMHS. ‡Dietary intakes were adjusted for total energy intake using the residual method.

with exercise and in the highest quintile of the HDS and 0.55 (95% CI 0.45–0.67) for those with exercise who had a sustained high HDS.

Results from sensitivity analyses were similar to the main results. The pooled HRs in the highest versus lowest quintile of HDS were 0.90 (95% CI 0.83–0.98) when only a baseline FFQ was used, 0.86 (95% CI 0.78–0.93) when the most recent FFQ was used, 0.85 (95% CI 0.76–0.94) when the first 2 years of follow-up were excluded, and 0.84 (95% CI 0.78–0.91) when all occurrences of self-reported diabetes were considered to be cases (all $P_{\text{continuous}}<0.001$). We also examined the associations of each contributing food group in the HDS with diabetes risk. In the multivariable and BMI-adjusted model, vegetables and dairy products showed significant inverse associations, while processed meat and refined grains showed significant positive associations (Supplementary Table 2). The results for individual food groups were all weaker than the result for the overall score, suggesting that the observed HDS-diabetes association was not driven by any single food group.

CONCLUSIONS

In this prospective analysis of diet quality and risk of type 2 diabetes among urban Chinese adults, a high HDS was associated with a 15% reduced risk of diabetes across extreme quintiles and a 25% reduced risk for individuals who maintained a healthy diet in the long term. The inverse association between HDS and diabetes was observed regardless of participants' age, sex, family history of diabetes, smoking and exercise habits, obesity status, and metabolic disease status, but individuals who also exercised in their leisure time appeared to benefit more. A sustained healthy diet plus exercise was associated with a 45% reduced risk. Our findings fill the current knowledge gap in dietary and lifestyle prevention of type 2 diabetes among Asian populations who have been experiencing a nutrition transition concurrent with a diabetes epidemic.

Several healthy diets have been associated with lower risk of the development of diabetes, including the Mediterranean diet, the DASH diet, a healthy vegetarian diet, and a diet following the *Dietary Guidelines for Americans* (3,5–7). These diets feature a common pattern characterized by high intakes of whole grains, fruits, vegetables, nuts, and legumes; moderate intakes of fish and dairy products; and low intakes of red and processed

Table 2—Long-term diet quality and risk of type 2 diabetes in the SWHS and SMHS (1996–2015)

	Quintile of the HDS*					
	Q1 (low)	Q2	Q3	Q4	Q5 (high)	$P_{continuous}$
Women						
HDS, median	18.0	21.8	24.0	27.0	31.0	
No. of cases/person-years	841/170,119	769/178,845	673/179,417	645/184,155	552/171,427	
Age- and energy-adjusted	1.00 (ref.)	0.90 (0.82–0.99)	0.83 (0.75–0.92)	0.80 (0.72–0.89)	0.72 (0.65–0.81)	<0.0001
Multivariable-adjusted†	1.00 (ref.)	0.93 (0.84–1.03)	0.88 (0.79–0.97)	0.86 (0.77–0.95)	0.80 (0.71–0.89)	<0.0001
Multivariable- and BMI-adjusted	1.00 (ref.)	0.97 (0.88–1.07)	0.92 (0.83–1.02)	0.90 (0.81–1.00)	0.85 (0.76–0.95)	<0.0001
Men						
HDS, median	18.0	21.5	24.0	27.0	31.0	
No. of cases/person-years	542/88,724	580/97,378	527/93,180	528/96,757	454/95,156	
Age- and energy-adjusted	1.00 (ref.)	0.98 (0.87–1.10)	0.93 (0.82–1.04)	0.89 (0.79–1.01)	0.78 (0.68–0.88)	<0.0001
Multivariable-adjusted	1.00 (ref.)	1.01 (0.90–1.14)	0.98 (0.87–1.11)	0.98 (0.86–1.11)	0.86 (0.76–0.99)	0.003
Multivariable- and BMI-adjusted	1.00 (ref.)	1.02 (0.91–1.15)	0.99 (0.88–1.12)	0.98 (0.86–1.10)	0.85 (0.74–0.97)	0.002
Pooled‡						
HDS, median	18.0	21.5	24.0	27.0	31.0	
No. of cases/person-years	1,383/258,843	1,349/276,223	1,200/272,597	1,173/280,912	1,006/266,583	
Age- and energy-adjusted	1.00 (ref.)	0.93 (0.86–1.00)	0.87 (0.80–0.94)	0.84 (0.78–0.91)	0.74 (0.69–0.81)	<0.0001
Multivariable-adjusted	1.00 (ref.)	0.96 (0.89–1.04)	0.92 (0.85–1.00)	0.91 (0.84–0.98)	0.83 (0.76–0.90)	<0.0001
Multivariable- and BMI-adjusted	1.00 (ref.)	0.99 (0.92–1.07)	0.95 (0.88–1.02)	0.93 (0.86–1.01)	0.85 (0.78–0.92)	<0.0001

Data are HR (95% CI) unless otherwise stated. ref., reference. *Cumulative average of the HDS based on data from repeated FFQs. †The Cox model was stratified by follow-up periods and adjusted for total energy intake, education, income, smoking, alcohol drinking, leisure-time exercise, family history of diabetes, history of hypertension, history of dyslipidemia, and, in women, menopausal status. Information on smoking, alcohol drinking, physical activity, hypertension, dyslipidemia, BMI, and menopausal status was updated during follow-up and modeled as time-varying variables. ‡Results among women and men were combined using fixed-effect meta-analysis, given that there was no significant heterogeneity by sex.

meat, refined grains, and sugar-sweetened beverages. The results of our present study support and complement existing evidence showing the beneficial effects of a healthy plant-based diet on the prevention of type 2 diabetes. Although the benefits of healthy eating on diabetes prevention are universal, the relations between specific dietary patterns and diabetes risk may be population specific, possibly due to varied dietary habits across regions and racial/ethnic groups and different population characteristics related to diabetes pathophysiology (5,8). For example, although promising antidiabetic effects of the Mediterranean diet have been shown in several European cohort studies and in a large clinical trial conducted in Spain (22–25), weak or null associations have been found in several studies conducted in non-Mediterranean countries, including the Whitehall II study in the U.K. and the Multi-Ethnic Study of Atherosclerosis

Table 3—Changes in the HDS and risk of type 2 diabetes in the SWHS and SMHS (1996–2015)

	Changes in the HDS*				
	Low-low	High-low	Medium	Low-high	High-high
Women					
HDS, median†	17.0	24.0	24.5	24.5	32.0
No. of cases/person-years	329/51,274	222/44,669	2,003/434,031	212/45,874	173/48,756
Age- and energy-adjusted	1.00 (ref.)	0.85 (0.74–1.00)	0.79 (0.70–0.89)	0.81 (0.68–0.96)	0.64 (0.53–0.77)
Multivariable-adjusted‡	1.00 (ref.)	0.92 (0.77–1.09)	0.85 (0.76–0.96)	0.85 (0.71–1.01)	0.73 (0.60–0.88)
Multivariable- and BMI-adjusted	1.00 (ref.)	0.95 (0.80–1.13)	0.90 (0.80–1.02)	0.90 (0.76–1.07)	0.78 (0.65–0.95)
Men					
HDS, median	17.0	24.5	24.0	24.0	31.5
No. of cases/person-years	158/21,996	146/24,881	1,056/177,000	117/19,867	129/30,907
Age- and energy-adjusted	1.00 (ref.)	0.82 (0.66–1.03)	0.83 (0.70–0.98)	0.83 (0.65–1.05)	0.58 (0.46–0.73)
Multivariable-adjusted	1.00 (ref.)	0.90 (0.72–1.13)	0.90 (0.76–1.06)	0.88 (0.69–1.12)	0.67 (0.52–0.85)
Multivariable- and BMI-adjusted	1.00 (ref.)	0.91 (0.72–1.14)	0.90 (0.76–1.07)	0.89 (0.70–1.14)	0.66 (0.52–0.85)
Pooled‡					
HDS, median	17.0	24.0	24.5	24.5	32.0
No. of cases/person-years	533/83,537	343/66,123	3,006/597,889	344/67,841	320/83,863
Age- and energy-adjusted	1.00 (ref.)	0.84 (0.73–0.96)	0.80 (0.73–0.89)	0.81 (0.71–0.94)	0.61 (0.53–0.71)
Multivariable-adjusted	1.00 (ref.)	0.91 (0.79–1.05)	0.87 (0.79–0.96)	0.86 (0.74–0.99)	0.70 (0.61–0.82)
Multivariable- and BMI-adjusted	1.00 (ref.)	0.93 (0.81–1.07)	0.90 (0.82–1.00)	0.90 (0.78–1.03)	0.74 (0.63–0.85)

Data are HR (95% CI) unless otherwise stated. ref., reference. *Low-low or high-high group was defined as staying in the lowest or highest quintile of the HDS in all dietary assessments. Low-high or high-low group was defined as the HDS changing from 1st/2nd to 4th/5th quintiles or from 4th/5th to 1st/2nd quintiles between adjacent FFQ assessments. The medium group included those who stayed in the 2nd to 4th quintile or who had small changes in the HDS (e.g., moved one quintile). †Median value of the cumulative average of the HDS. ‡Adjusted for the same covariates as shown in the footnote of Table 2. Results among women and men were combined using a fixed-effect meta-analysis, given that there was no significant heterogeneity by sex.

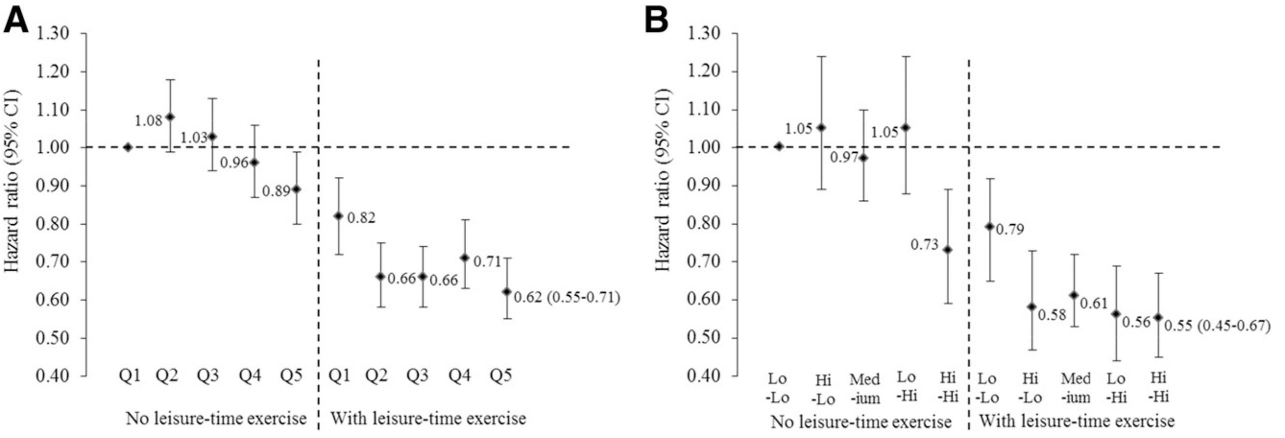

Figure 1—Joint effects of a healthy diet and leisure-time exercise on risk of type 2 diabetes in the SWHS and SMHS (1996–2015). Participants who had no leisure-time exercise and the least healthy diet (Q1 in panel *A*; Lo-Lo in panel *B*) were the reference group. The Cox model was adjusted for the same covariates as shown in footnote of Table 2. The definitions of Lo-Lo, Hi-Lo, Medium, Lo-Hi, and Hi-Hi groups are the same as shown in the footnote of Table 3. Results among women and men were combined using fixed-effect meta-analysis. Hi, high; Lo, low; Q, quintile.

(MESA), Multiethnic Cohort (MEC), and Women's Health Initiative (WHI) in the U.S. (26–29). Likewise, the DASH diet and the Alternate Healthy Eating Index (AHEI), designed based on findings from non-Hispanic white Americans, failed to show significant associations with diabetes in the European Prospective Investigation into Cancer and Nutrition (EPIC) study and among racial/ethnic minority Americans including Hispanics, blacks, and Asian Americans (28–31). Significant heterogeneity in the diet-diabetes associations by country and by race/ethnicity has been reported in multiple studies (5,23,29,31,32). Therefore, large prospective studies among diverse populations and in different regions of the world are warranted. Evidence to date from Asian populations has been limited; only a few cohorts have conducted analyses in a subgroup of Asian American participants, and these yielded inconsistent results. For example, among women of Asian descent in the WHI, higher Healthy Eating Index (HEI)-2010 and AHEI scores were associated with a 20% reduced risk of diabetes, while DASH and Mediterranean diet scores showed insignificant results (29). By contrast, among Japanese-American women in the MEC, the DASH score was significantly associated with reduced diabetes risk, whereas the HEI-2010, AHEI, and Mediterranean diet scores showed no associations (28). To our knowledge, no similar studies have been conducted among populations living in fast-developing Asian countries.

Given that the existing dietary scores may not well reflect the dietary patterns of our study population and that the data-driven dietary clusters may be hard to interpret and not necessarily associated with disease outcome, we chose an a priori approach and developed a diet quality score based on eight food groups that were commonly consumed in our study population and have been suggested to be associated with diabetes risk (13–18). Furthermore, we believe that a food-based diet quality score (no nutrient component) has greater clinical and public health implications, because it is easy to understand and explain and can be calculated without using statistical software or food composition tables.

Our study participants, middle-aged and older Chinese adults living in urban Shanghai, traditionally have a high-carbohydrate, low-fat, and plant-rich diet (the typical southern Chinese diet). Carbohydrates provide the majority of daily calories in our study population—nearly 70%—compared with $<$50% in US populations. Meanwhile, the majority of carbohydrates in our cohorts are from refined grains (i.e., white rice and refined wheat products), which are high–glycemic index, high–glycemic load, low-fiber, and low-micronutrient staple foods. A high intake of refined grains has been consistently associated with increased diabetes risk in our cohorts and others (e.g., HR 1.37 [95% CI 1.11–1.69] in the highest vs. lowest quintile of intake in the SWHS) (13,33). A recent analysis using nationwide data from the China Health and Nutrition Survey further suggested that high refined grain intake is the leading dietary risk factor for diabetes burden in China (34). On the other hand, our study participants also usually have high intakes of vegetables and legumes (especially green leafy vegetables and soybean products), with average consumptions of 250–300 g (3–4 servings) of vegetables and 15–30 g (dry weight, 0.5–1 serving) of legumes per day. Vegetables and legumes have been shown to be the beneficial factors of traditional southern Chinese diet for diabetes prevention (35–38). Meanwhile, since the 1980s, the rapid economic growth and social development of China, particularly in urban areas, have played a double-edged sword role for nutrition and diabetes prevention. The consumption of animal-source foods, including all kinds of meats and dairy products as well as fruit and nuts, has increased (39). The overall dietary pattern and diet quality remain/become suboptimal. As the Chinese diet and other traditional Asian diets continue to be Westernized, our findings may inform public health policy to promote a healthy plant-based diet (e.g., by replacing refined grains with whole grains and other healthy plant foods while limiting red and processed meat intake), which could have a significant impact on curbing the diabetes epidemic in China and other fast-developing Asian countries.

To our knowledge, the current study is the first prospective analysis of long-term diet quality and its changes in relation to the risk of type 2 diabetes among urban Chinese adults. The strengths of our study include a large sample size, prospective cohort design, repeated dietary assessments, and comprehensive adjustments for covariates that were also updated during cohort follow-up. The repeated surveys not only provided better assessments of usual diet and other lifestyle habits but also allowed us to examine potential changes in diet over time and evaluate diabetes risk among extreme groups of participants who had a consistently high- or low-quality diet. We censored the observation if cardiovascular disease or cancer developed in a participant to avoid the potential influences of diet and lifestyle changes and disease treatments on the risk estimates. Our results are robust in a series of stratified analyses and sensitivity analyses. Moreover, as mentioned earlier, we developed an overall diet quality score based on food groups, which may be relatively easy to apply in clinical and educational settings.

Several limitations merit discussion. First, as in all observational studies, measurement errors are inevitable. Repeated measures would overcome some of the errors, as it was evident that the HDS-diabetes association was stronger when using the cumulative average of diet than when using the single baseline diet. Also, although moving one category in food consumption or HDS may be due to reporting errors, a consistent category is more likely to reflect true intakes and a change of two categories or more may reflect real dietary changes. Second, although all eight food groups have been suggested to be associated with diabetes risk, many food-diabetes associations remain inconclusive including for fish, fruits, vegetables, and dairy products (14,15,17). Heterogeneity has been found across studies by geographic location (e.g., U.S. vs. Europe vs. Asia), and usually studies among Asian populations were limited. We thus chose an unweighted dietary score given the current mixed evidence and uncertain effect sizes of food-diabetes associations. Third, our diabetes case patients were identified based on participants' answers to five questions regarding their physician diagnosis, glucose tests, diabetes symptoms, and medication use. This method has been found to have high specificity (98%) but moderate sensitivity (58%) in a similar population of middle-aged and older urban Chinese adults (40). Thus, we might have underestimated incident diabetes, but such nondifferential misclassification is more likely to attenuate our results. We are developing methods incorporating electronic medical records to help identify and verify diabetes cases for future studies in our cohorts. Fourth, although we carefully adjusted for multiple potential confounders, we cannot exclude the possibility of residual confounding, nor can we completely separate the effect of diet from other health behaviors related to diabetes. The significant interaction and the joint effect between diet and exercise observed in this study suggested a potential synergistic effect of dietary and other lifestyle factors on diabetes prevention. Finally, our study participants are 40- to 74-year-old urban Chinese adults; hence, the present results might not be directly generalizable to rural and younger Chinese populations, who may have different dietary habits. However, our results are consistent with the overall literature and studies conducted among representative samples of general Chinese populations (37,38).

In summary, the current study is the first large prospective analysis of long-term diet quality and risk of type 2 diabetes among urban Chinese adults. Our findings suggest that a healthy diet, rich in vegetables, fruits, dairy products, nuts, legumes, and fish/seafood and low in refined grains, red meat, and processed meat, is associated with a 15–25% reduced risk of diabetes. Individuals who maintain a healthy diet in the long term and also exercise may benefit the most, showing a 45% reduced risk. Our findings provide strong evidence supporting the importance of healthy eating in the prevention of type 2 diabetes among Chinese and likely other Asian populations.

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Author Contributions. D.Y. contributed to the study concept and design, statistical analysis, results interpretation, and drafting and revision of the manuscript and approved the final version of the manuscript. W.Z., H.C., Y.-B.X. H.L., Y.-T.G., and X.-O.S. contributed to the study concept and design, results interpretation, and revision of the manuscript and approved the final version of the manuscript. D.Y. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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