Diet Quality Is Linked to Insulin Resistance among Adults in China

Zhihong Wang,[1,3] Linda S Adair,[1] Jianwen Cai,[2] Penny Gordon-Larsen,[1] Anna Maria Siega-Riz,[1] Bing Zhang,[3] and Barry M Popkin[1]

Departments of [1]Nutrition, Carolina Population Center, and [2]Biostatistics, University of North Carolina at Chapel Hill, Chapel Hill, NC; and [3]National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention, Beijing, China

Abstract

Background: Little is known about the impact of Chinese diet quality changes on diabetes-related markers.

Objective: The present study examined the association of changes in overall diet quality with various biomarkers of diabetes among adults in China.

Methods: The current analysis used longitudinal diet data from 1991 to 2006 and fasting blood samples from 2009 for 4734 adults aged 18–65 y from the China Health and Nutrition Survey. Dietary intake was assessed by using 3 consecutive 24-h recalls and household food weighing. The tailored Alternative Healthy Eating Index (tAHEI) was adapted from the 2010 Harvard Alternative Healthy Eating Index to measure overall diet quality. We categorized baseline tAHEI scores into tertiles and annual changes in the scores into 5 levels (high decrease, low decrease, maintain, low increase, and high increase). We performed mixed-effects regressions to assess the associations between baseline scores and changes in the tAHEI scores and diabetes or insulin markers.

Results: Adults with high baseline tAHEI scores tended to be male, older, of lower socioeconomic status, and with higher physical activity levels. After adjustment for all of the covariates, insulin and homeostasis model assessment of insulin resistance (HOMA-IR) values were 5.1% (95% CI: −0.100, −0.002) and 5.7% (95% CI: −0.113, −0.001) lower, respectively, for adults with high compared with low baseline tAHEI scores and 8.6% (95% CI: −0.155, −0.017) and 9.8% (95% CI: −0.177, −0.018) lower, respectively, for adults with a high increase in score compared with the ''maintain'' category. Null associations were observed between baseline scores and changes in the scores and fasting blood glucose, glycated hemoglobin (HbA1c), and diabetes prevalence.

Conclusions: Baseline and changes in diet quality were independently associated with lower HOMA-IR and plasma insulin but not with fasting blood glucose and HbA1c in Chinese adults. Prospective studies on overall diet quality in relation to diabetes markers and risk of diabetes are needed. *J Nutr* 2017;147:2102–8.

Keywords: China, diet quality, fasting blood glucose, HbA1c, insulin resistance

Introduction

Several nationally representative surveys in China reported that the prevalence of diabetes in adults was 0.67% in 1984, 2.5% in 1994, and 9.7% in 2010 (1–3). Diabetes mortality and disability-adjusted life-years between 1990 and 2000 increased by 45.0% and 10.3%, respectively (4). The prevention and treatment of diabetes has become a public health priority. The WHO emphasizes the essential role of diet, together with alcohol consumption, smoking, and physical activity (PA), in relation to diabetes risk (5). Over the past 2 decades, China has experienced marked shifts in diet (6, 7) and PA (8, 9) along with the country's rapid economic growth and social changes and the concurrent shifts in disease patterns (7). Chinese adults' diet has shown rapid declines in the intakes of coarse grains, vegetables, and legumes and increases in the intakes of edible oils and animal-source foods. (6, 7, 10). Considering the multidimensional shifts in the Chinese diet, the key issue is how to relate the

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Supplemental Tables 1–4 are available from the ''Online Supporting Material'' link in the online posting of the article and from the same link in the online table of contents at http://jn.nutrition.org.

Address correspondence to BMP (e-mail: popkin@unc.edu).

Abbreviations used: AHEI-2010, 2010 Alternative Healthy Eating Index; CHNS, China Health and Nutrition Survey; HbA1c, glycated hemoglobin; PA, physical activity; SSB, sugar-sweetened beverage; tAHEI, tailored Alternative Healthy Eating Index.

dynamic complexity of food consumption as a whole to diabetes risk in China.

Many studies emphasized the relevant role of overall diet quality in predicting diabetes and suggested that index-based dietary patterns capture the overall complexity of the diet and allow for standardization of the scores and comparability of results across studies from different populations (11). The 2010 Alternative Healthy Eating Index (AHEI-2010) was created on the basis of the recommendations of Harvard Healthy Eating Pyramid, an evidence-based healthy dietary guidance (12–15). Previous studies indicated a 33% lower risk of diabetes related to higher AHEI-2010 scores in the Nurses' Health Study and the Health Professionals Follow-Up cohorts (15, 16). The study by Jacobs et al. (17) in the Hawaiian component of the cohort suggested that a higher AHEI-2010 score was related to a 13–28% lower risk of type 2 diabetes in white but not in Japanese-American and Native Hawaiian participants aged 45–75 y. One study found no association of baseline diet quality in 2006, measured by the adapted version of the Harvard AHEI-2010 for the Chinese diet, with diabetes prevalence in Chinese adults in 2009 (18). How long-term changes in Chinese diet quality are related to diabetes risk remains unclear. This study used repeat dietary data for 4734 adults between 1991 and 2006 to examine the association between baseline and changes in diet quality, measured by the tailored Alternative Healthy Eating Index (tAHEI), and diabetes-related markers obtained in 2009, including glycated hemoglobin (HbA1c), glucose, insulin, and HOMA-IR.

Methods

The China Health and Nutrition Survey. Initiated in 1989, the China Health and Nutrition Survey (CHNS) focuses on assessing the relations between the social and economic transformation in China and the resulting effects on the health and nutritional status of the population (11, 19). The CHNS used a multistage random-cluster process to draw the sample from 8 provinces; 24 communities in each province were randomly selected as the primary sampling units. In each type of community, 20 households were randomly selected, and all individuals in the household were surveyed for all data in each wave. Survey procedures have been described in detail elsewhere (19, 20). The CHNS completed 7 rounds from 1991 to 2009 (1991, 1993, 1997, 2000, 2004, 2006, and 2009). The 2009 survey was the first to collect fasting blood samples. The protocols of the survey were approved by the institutional review committees at the University of North Carolina at Chapel Hill, the China-Japan Friendship Hospital, the Ministry of Health and China, and the National Institute of Nutrition and Health at the Chinese Center for Disease Control and Prevention. All of the participants provided written informed consent.

Study population. The present analysis selected adults aged 18 to 65 y at study entry who had ≥2 waves of dietary data from 1991 to 2006 and complete diabetes-related biomarkers at the 2009 examination. After excluding women who were pregnant or lactating during a survey year and those with implausible energy intakes (<800 or >6000 kcal/d for men and <600 or >4000 kcal/d for women) (21), implausible biomarker values, missing baseline sociodemographic variables, and baseline diagnosed diabetes, our final sample included 4734 participants (2263 men, 2471 women).

Assessment of diet quality. Dietary intake was assessed by collecting 3 consecutive 24-h recalls for each person, a household weighing inventory of all available foods over the same 3 periods, and an interviewer-administered past-year FFQ for sugar-sweetened beverages (SSBs) and fruit juices since 2004 and alcohol consumption since 1993. The dietary data collection details are described elsewhere (22, 23).

We used the tAHEI, adapted from the Harvard AHEI-2010 (15), to assess diet quality. The adaptation methods are described in detail elsewhere. In general, major adaptations included the following: *1*) change in scale from serving to grams for vegetables, whole fruit, nuts and legumes, red and processed meat, SSBs, and fruit juices; *2*) estimation of alcohol, SSB, and fruit juice intakes from the past-year FFQ in available survey years to reduce the potential underestimation of 24-h recall due to episodic consumption; *3*) replacing the whole-grain component with a cereal-fiber component due to extremely low intake and lack of variation in Chinese adults; *4*) scaling only fresh red meat intake to increase the variation given that Chinese processed red meat intake is extremely low (~3.1% of total meat) and few adults consumed >64 g of processed meat (24); *5*) linking all Chinese foods to the US Food and Nutrient Database for Dietary Studies (25) and the National Nutrient Database for Standard Reference (26) to estimate PUFAs and long-chain (ω-3) FA intake; and *6*) omitting the *trans* fat component in the tAHEI because of a lack of information on *trans* fat composition of all consumed foods in both the Chinese and USDA food-composition tables. **Supplemental Table 1** shows the components and scaling methods of the tAHEI. We used the 3-d average intakes of total energy, nutrients, and food groups to calculate total tAHEI scores ranging from 0 to 100. A higher score indicates better diet quality.

Assessment of baseline tAHEI score and changes in tAHEI score. The CHNS is an open-cohort study, and participants have different entry times. We regarded the entry time of each participant as baseline data. We categorized baseline tAHEI scores of the participants into tertiles (low, medium, and high). Annual changes in tAHEI scores were calculated as the difference between the score at the end year of follow-up and the baseline score divided by years of follow-up. We classified the participants into 5 categories: high decrease (decrease in tAHEI score per year of >1.5 points), low decrease (decrease in score of between 0.5 and 1.5 points), maintain (change in score within 0.5 point of baseline), low increase (increase in score of between 0.5 and 2.0 points), and high increase (increase in score of >2.0 points). Percentages of adults in high-decrease, low-decrease, maintain, low-increase, and high-increase categories were 10.1%, 17.0%, 37.4%, 25.6%, and 10.0%, respectively.

Assessment of diabetes-related markers. In the 2009 CHNS, overnight-fasting blood samples were collected via venipuncture by trained experienced physicians, phlebotomists, or nurses. Plasma and serum samples were frozen and stored at −86°C for later laboratory analysis. All of the samples were analyzed with strict quality control.

Whole blood was immediately centrifuged, and serum was tested for glucose by using a glucose oxidase phenol 4-aminoantipyrine peroxidase kit (Randox) and a Hitachi 7600 analyzer (Hitachi). Serum insulin was tested by using a radioimmunology assay kit (North Institute of Biological Technology) with the use of an XH-6020 gamma counter (North Institute of Biological Technology). Whole-blood HbA1c was measured by HPLC with an automated glycohemoglobin analyzer (model HLC-723 G7; Tosoh). HOMA-IR was estimated as follows: [fasting insulin (μU/mL) × fasting blood glucose (mmol/L)]/22.5. Diabetes was defined on the basis of HbA1c ≥6.5% and fasting blood glucose ≥7.0 mmol/L. Fasting blood glucose, HbA1c, insulin, and HOMA-IR were ln-transformed to fit a relatively normal distribution.

Covariates. Trained interviewers used standard questionnaires to collect baseline information on annual family income, individual educational level, PA, smoking status, and community information. We calculated per capita annual family income by dividing annual family income by household size in each wave. The community urbanicity index, a complex measure of urbanization, is based on 12 multidimensional components reflecting the heterogeneity in economic, social, demographic, and infrastructural changes at the community level (27).

PA includes 4 domains: occupational, household chores, leisure time, and transportation activities. All of the activities were reported in average hours per week during the past year (9). We converted time spent in each activity into metabolic equivalent task hours per week based on the Compendium of Physical Activities (28). The metabolic equivalent task hours per week measurement accounts for the average intensity and time spent in each activity. We also considered age in 2006, sex, a geographical factor (northern, central, and southern provinces), baseline education, and smoking status as potential covariates.

Statistical analysis. We first summarized component scores across levels of baseline tAHEI scores and component scores at baseline and at the end of follow-up across levels of changes in scores. Then we compared sociodemographic factors, lifestyle factors, and diabetes-related biomarkers across levels of baseline scores. We performed general linear regressions for the overall test of statistical significance for each component score, continuous demographic factors, and continuous diabetes-related markers and conducted pairwise comparison of multiple groups with Bonferroni adjustment across levels of baseline tAHEI scores, whereas chi-square tests were used for categorical variables.

Next, we tested but found no significant interactions between levels of annual changes in tAHEI scores with levels of baseline tAHEI scores. We performed a series of mixed-effects linear models to examine the association of the baseline and annual changes in tAHEI scores with continuous diabetes-related markers, low baseline scores, or maintenance of scores as the reference categories, respectively. Random intercepts were included to account for community-level clustering. We conducted the mixed-effects logistic models for diabetes prevalence. We adjusted for demographic, socioeconomic, and lifestyle factors, in turn, to check the change in coefficients, considering their potential confounding.

Because ln-transformed markers were the outcome, the regression coefficients were multiplied by 100 and interpreted as the percentage change in each marker for being in a certain level of the scores compared with the reference group. We fitted mixed-effects linear and logistic models by using STATA 14.1 (StataCorp). For all other descriptive analyses, we used SAS 9.4 (SAS Institute). All of the statistical tests were 2-tailed and considered significant at $P < 0.05$.

Results

Component score profiles of baseline and average annual changes in tAHEI scores. As shown in **Supplemental Table 2**, participants with high baseline tAHEI scores had an average score of 45.3, which was 17.3 and 9.2 points higher than participants with low and medium baseline scores, respectively (P-trend < 0.0001). In addition, the scores for nuts and legumes, cereal fiber, and sodium contributed more to the disparity in baseline scores.

For annual changes in tAHEI scores, participants in the high-decrease group showed large declines in scores for nuts and legumes, fresh red meat, and sodium (all P-trend < 0.0001), whereas those in the high-increase group showed large increases in scores for nuts and legumes, PUFAs, and EPA plus DHA (all P-trend < 0.0001).

Demographic and lifestyle characteristics across levels of baseline and annual changes in the tAHEI score. In comparison with participants with low baseline tAHEI scores, those with high baseline scores were older, had attained fewer years of education, and were more likely to be male, have a lower income, have a higher PA level, and live in the central region and low urbanized communities (**Supplemental Table 3**). For annual changes in tAHEI scores, compared with participants in other categories, those in the high increase category were younger, had attained more years of education, and were more likely to be male, have a higher income, have a lower PA level, and live in highly urbanized communities in the central or south regions (**Supplemental Table 4**).

Diabetes and insulin markers in 2009 across levels of baseline tAHEI scores. In comparison with participants with low baseline tAHEI scores, those with high baseline tAHEI scores tended to have higher log-transformed HbA1c (P-trend < 0.0001) but lower log-transformed insulin (P-trend < 0.001) and HOMA-IR (P-trend < 0.05), whereas log-transformed fasting blood glucose was not significantly different across baseline score tertiles (P-trend = 0.19) (**Table 1**). Diabetes prevalence, defined by fasting blood glucose and HbA1c, was not significantly different across baseline score tertiles (Table 1).

Association between baseline tAHEI score and diabetes-related markers. After adjustment for all potential covariates, insulin and HOMA-IR values were significantly lower in participants with high compared with low baseline tAHEI scores by 5.1% (95% CI: −0.100, −0.002) and 5.7% (95% CI: −0.113, −0.001), respectively, whereas null associations of baseline tAHEI score were observed with fasting blood glucose and HbA1c (**Table 2**).

Association between annual changes in tAHEI scores and diabetes-related markers. **Table 3** shows that annual changes in tAHEI scores were negatively associated with insulin and HOMA-IR after adjustment for all potential covariates. Model 4 shows that there were significantly lower insulin (7.1%; 95% CI: −0.139, −0.002) and HOMA-IR (8.1%; 95% CI: −0.159, −0.003) values in the high-increase group compared with the maintain group, after adjustment for all sociodemographic and lifestyle factors. Model 5 shows that additional adjustment for baseline score enhanced the magnitude of association (log insulin: −0.086; 95% CI: −0.155, −0.017; log HOMA-IR: −0.098; 95% CI: −0.177, −0.018). There were no associations between annual changes in scores and log-transformed glucose and HbA1c.

Baseline and annual changes in tAHEI scores and diabetes prevalence. As shown in **Table 4**, high decreases (OR: 0.605; 95% CI: 0.368, 0.994) and low increases (OR: 0.691; 95% CI: 0.516, 0.925) in tAHEI score were negatively associated with the prevalence of diabetes defined by fasting blood glucose compared with the maintain score, after adjustment for sociodemographic and lifestyle factors and baseline score (model 5). However, baseline tAHEI score was not associated with the prevalence of diabetes defined by HbA1c and fasting blood glucose, and annual changes in score were not associated with the prevalence of diabetes defined by HbA1c.

Discussion

In this study, we investigated the association between baseline and annual changes in diet quality during the follow-up period from 1991 to 2006 and diabetes markers in 2009 in Chinese adults aged 18–65 y. We found that participants with low socioeconomic status and in low-urbanized communities tended to have relatively high baseline diet quality (45.3 of 100 points); approximately one-third of the participants maintained their diet quality and one-fourth showed minor improvements during the follow-up period. Our study also found that high baseline diet quality was associated with ∼5.1% and 5.7% lower insulin and HOMA-IR values compared with low baseline diet quality, whereas a high increase in diet quality, independently from baseline diet quality, was associated with ∼8.6% and 9.8% lower insulin and HOMA-IR values compared with the

TABLE 1 Diabetes and insulin markers by baseline tAHEI score in Chinese adults: 2009 CHNS[1]

	Baseline tAHEI score			
	Low	Medium	High	*P*
Participants, *n* (%)	1578 (33.3)	1578 (33.3)	1578 (33.3)	
Median score (IQR)	28.7 (25.6, 30.9)	31.0 (34.5, 37.6)	44.2 (41.7, 47.6)	
Log plasma glucose, mmol/L	4.56 ± 0.20[2]	4.55 ± 0.19	4.55 ± 0.21	0.19
Log HbA1c	1.71 ± 0.12	1.72 ± 0.14	1.73 ± 0.14	<0.001
Log plasma insulin, μIU/mL	2.40 ± 0.66	2.33 ± 0.67	2.33 ± 0.67	<0.01
Log HOMA-IR	0.96 ± 0.76	0.87 ± 0.75	0.88 ± 0.77	<0.01
Diabetes defined by HbA1c, %	6.21	6.21	7.29	0.37
Diabetes defined by fasting plasma glucose, %	6.34	6.08	6.91	0.62

[1] Significance for marker heterogeneity was determined by using a nonparametric median test, for diabetes prevalence by using chi-square tests, and for logarithmically transformed markers by using general linear models to test *P*-trend across baseline tAHEI score tertiles. CHNS, China Health and Nutrition Survey; HbA1c, glycated hemoglobin; tAHEI, tailored Alternative Healthy Eating Index.
[2] Mean ± SD for logarithmically transformed markers (all such values).

maintain group. However, we found no association between baseline and changes in diet quality scores and fasting blood glucose and HbA1c. These findings suggest that a high diet quality at baseline and an annually improved diet quality may have potential benefits on improvement of insulin resistance. Longitudinal research on the relation of diet quality and diabetes markers is needed to confirm our results.

Our study found a nonlinear association between annual changes of the score and diabetes prevalence, 39.5% and 30.9% lower prevalence of diabetes (defined by fasting blood glucose only) in the adults in the categories of low increase and high decrease compared with those in the maintain category, respectively. Several studies suggested a negative linear association of an increased AHEI-2010 score with diabetes risk, such as the 33% lower risk of diabetes in the Nurses' Health Study and the Health Professionals Follow-Up Study 24-y follow-up cohorts (15, 16) and a 13–28% lower risk of type 2 diabetes in white but not in Japanese-American and Native Hawaiian participants aged 45–75 y (17). There are several possible reasons for these inconsistent results. First, the AHEI-2010 was not based on evidence of diet-disease relations in Asian populations, and the evidence-based threshold effect of diabetes-related components of the AHEI-2010 in the Western population may not be the case for the Chinese population.

TABLE 2 Associations between levels of baseline tAHEI score and log fasting plasma glucose, HbA1c, plasma insulin, and HOMA-IR in Chinese adults: 2009 CHNS[1]

	Model 1	Model 2	Model 3
Log plasma glucose, mmol/L			
Low	Ref	Ref	Ref
Medium	−0.006 (−0.020, 0.008)	−0.009 (−0.023, 0.005)	−0.008 (−0.022, 0.006)
High	−0.001 (−0.016, 0.014)	−0.008 (−0.023, 0.007)	−0.007 (−0.023, 0.008)
P-trend	0.92	0.34	0.36
Log HbA1c			
Low	Ref	Ref	Ref
Medium	0.004 (−0.005, 0.013)	0.001 (−0.008, 0.010)	0.001 (−0.008, 0.010)
High	0.010 (0.000, 0.019)*	0.004 (−0.006, 0.013)	0.003 (−0.006, 0.013)
P-trend	0.04	0.42	0.47
Log plasma insulin, μIU/mL			
Low	Ref	Ref	Ref
Medium	−0.045 (−0.091, 0.000)	−0.046 (−0.092, −0.000)*	−0.043 (−0.089, 0.002)
High	−0.053 (−0.101, −0.005)*	−0.052 (−0.101, −0.003)*	−0.051 (−0.100, −0.002)*
P-trend	0.04	0.04	0.05
Log HOMA-IR			
Low	Ref	Ref	Ref
Medium	−0.051 (−0.103, 0.001)	−0.055 (−0.107, −0.002)*	−0.052 (−0.104, 0.001)
High	−0.053 (−0.108, 0.002)	−0.059 (−0.115, −0.003)*	−0.057 (−0.113, −0.001)*
P-trend	0.07	0.05	0.05

[1] Values are β coefficients (95% CIs); *n* = 4734. Baseline tAHEI scores are categorized into tertiles (low, medium, and high), with "low" as the reference group. The regression coefficients were multiplied by 100 and interpreted as the percentage of change in each marker for being in the medium or high baseline score category compared with the low baseline score category. Model 1 was the crude unadjusted model. Model 2 adjusted for age in 2006, sex, baseline income (tertiles), education, geographic region, and baseline urbanicity index (tertiles). Model 3 additionally adjusted for baseline physical activity (tertiles), smoking status, and baseline energy intake. Fasting glucose, HbA1c, insulin, and HOMA-IR were logarithmically transformed. *P*-trend was calculated by assigning median values to tertiles of baseline tAHEI score, and this variable was entered as a continuous term in the models. **P* < 0.05. CHNS, China Health and Nutrition Survey; HbA1c, glycated hemoglobin; Ref, reference; tAHEI, tailored Alternative Healthy Eating Index.

TABLE 3 Associations between levels of annual change in tAHEI scores and log fasting glucose, HbA1c, insulin, and HOMA-IR in Chinese adults: 2009 CHNS[1]

	Model 1	Model 2	Model 3
Log plasma glucose, mmol/L			
High decrease	−0.026 (−0.046, −0.006)*	−0.015 (−0.035, 0.006)	−0.014 (−0.036, 0.007)
Low decrease	−0.008 (−0.025, 0.009)	−0.006 (−0.023, 0.011)	−0.005 (−0.022, 0.012)
Maintain	Ref	Ref	Ref
Low increase	−0.004 (−0.019, 0.010)	−0.003 (−0.017, 0.012)	−0.004 (−0.019, 0.011)
High increase	−0.019 (−0.040, 0.001)	−0.009 (−0.030, 0.012)	−0.012 (−0.034, 0.010)
P-trend	0.76	0.69	0.98
Log HbA1c			
High decrease	−0.015 (−0.027, −0.002)*	−0.005 (−0.017, 0.008)	−0.007 (−0.020, 0.007)
Low decrease	−0.002 (−0.012, 0.009)	−0.000 (−0.010, 0.010)	−0.002 (−0.012, 0.009)
Maintain	Ref	Ref	Ref
Low increase	−0.004 (−0.013, 0.005)	−0.002 (−0.011, 0.007)	−0.001 (−0.011, 0.008)
High increase	−0.014 (−0.027, −0.001)*	−0.004 (−0.017, 0.009)	−0.004 (−0.017, 0.010)
P-trend	0.72	0.89	0.843
Log plasma insulin, μIU/mL			
High decrease	−0.001 (−0.066, 0.063)	−0.024 (−0.090, 0.043)	−0.010 (−0.080, 0.059)
Low decrease	−0.016 (−0.069, 0.038)	−0.020 (−0.073, 0.033)	−0.008 (−0.063, 0.047)
Maintain	Ref	Ref	Ref
Low increase	0.013 (−0.034, 0.059)	0.011 (−0.036, 0.057)	−0.001 (−0.048, 0.047)
High increase	−0.042 (−0.107, 0.024)	−0.066 (−0.134, 0.002)	−0.086 (−0.155, −0.017)*
P-trend	0.57	0.49	0.08
Log HOMA-IR			
High decrease	−0.028 (−0.102, 0.046)	−0.038 (−0.114, 0.038)	−0.025 (−0.105, 0.054)
Low decrease	−0.024 (−0.085, 0.037)	−0.026 (−0.087, 0.035)	−0.014 (−0.077, 0.049)
Maintain	Ref	Ref	Ref
Low increase	0.009 (−0.045, 0.062)	0.008 (−0.045, 0.062)	−0.004 (−0.059, 0.051)
High increase	−0.062 (−0.137, 0.013)	−0.075 (−0.153, 0.003)	−0.098 (−0.177, −0.018)*
P-trend	0.66	0.63	0.14

[1] Values are β coefficients (95% CIs); $n = 4734$. Changes in tAHEI score per year are categorized into 5 levels, with ''maintain'' as the reference group. The regression coefficients were multiplied by 100 and interpreted as the percentage of change in each marker for being in any category of annual change in score compared with the maintain category. Model 1 was the crude unadjusted model. Model 2 adjusted for age in 2006, sex, baseline income (tertiles), education, geographic region, and baseline urbanicity index (tertiles). Model 3 additionally adjusted for baseline physical activity (tertiles), smoking status, baseline energy intake, and levels of baseline score. Glucose, HbA1c, insulin, and HOMA-IR were logarithmically transformed. *P*-trend was calculated by assigning median values to each level of annual change in tAHEI scores, and this variable was entered as a continuous term in the models. *$P < 0.05$. CHNS, China Health and Nutrition Survey; HbA1c, glycated hemoglobin; Ref, reference; tAHEI, tailored Alternative Healthy Eating Index.

Second, the adapted version of the tAHEI was not identical to the original Harvard AHEI-2010 because of several methodologic adaptations to the Chinese diet and food-composition tables (15, 18). Third, component profiles of baseline score tertiles need to be considered, especially for those components that have been suggested to be associated with diabetes risk, including vegetables and fruit, SSBs, fresh red meat, and cereal fibers. The high baseline score category was 4.6, 3.5, and 3.0 points higher for nuts and legumes, fresh red meat, and cereal fiber, respectively, compared with the low baseline score category, and there were only slight differences in scores for vegetables, SSBs, and fruit juices, which had low discriminating ability in relation to diabetes risk. Some studies indicated that processed meat, rather than unprocessed red meat, was associated with a higher risk of diabetes (29). In addition, one study suggested that the effect of some diabetes-associated components may be diluted in an index consisting of other components (30).

Our study has important strengths, including relatively precise estimates of dietary intakes from the combination of multiple assessment methods that remained consistent over the period of the CHNS and the long follow-up period and prospective design of changes in diet quality between 1991 and 2006 in relation to diabetes markers in 2009. Our study also has several limitations. First, only one time point of diabetes-related markers in the 2009 CHNS was available. We did not know the exact time of diabetes onset and duration of the condition for participants. However, we removed baseline physician-diagnosed adults with diabetes and evaluated annual changes in diet quality with a maximum 15-y follow-up from 1991 to 2006 in relation to the diabetes markers in 2009, which may have reduced the possibility of dietary intake changes due to diabetes onset between 2006 and 2009. Related analyses that used the CHNS showed that ~40% of the participants with fasting blood diagnoses of diabetes in 2009 were diagnosed by a physician according to self-reported data. Of these, only one-third were being treated. Other studies on lifestyle changes related to diabetes in China showed minimal changes in behavior (31, 32). Second, we evaluated annual changes in diet quality with the use of 2 time points—baseline and the end of follow-up—without consideration of the potential fluctuations between time points. The entry year of the participants varied because of the open-cohort nature of the CHNS. Third, we categorized annual

TABLE 4 Associations between baseline tAHEI scores or annual changes in tAHEI scores and diabetes prevalence in Chinese adults: 2009 CHNS[1]

	Model 1	Model 2	Model 3
Diabetes defined by HbA1c			
Baseline tAHEI score			
Low	Ref	Ref	Ref
Medium	0.983 (0.728, 1.328)	0.904 (0.667, 1.225)	0.888 (0.653, 1.209)
High	1.113 (0.809, 1.531)	0.957 (0.690, 1.328)	0.933 (0.670, 1.299)
P-trend	0.50	0.84	0.73
Annual change in tAHEI score			
High decrease	0.628 (0.377, 1.047)	0.652 (0.388, 1.096)	0.631 (0.364, 1.095)
Low decrease	1.017 (0.730, 1.416)	1.025 (0.734, 1.431)	0.999 (0.698, 1.429)
Maintain	Ref	Ref	Ref
Low increase	1.054 (0.789, 1.409)	1.047 (0.780, 1.407)	1.043 (0.778, 1.397)
High increase	0.904 (0.589, 1.388)	0.910 (0.572, 1.450)	0.901 (0.559, 1.449)
P-trend	0.34	0.42	0.46
Diabetes defined by fasting glucose			
Baseline tAHEI score			
Low	Ref	Ref	Ref
Medium	0.958 (0.733, 1.250)	0.951 (0.724, 1.249)	0.950 (0.723, 1.249)
High	1.096 (0.815, 1.476)	1.029 (0.763, 1.388)	1.028 (0.763, 1.385)
P-trend	0.53	0.83	0.83
Annual change in tAHEI score			
High decrease	0.603 (0.369, 0.984)*	0.619 (0.379, 1.011)	0.605 (0.368, 0.994)*
Low decrease	0.937 (0.686, 1.279)	0.954 (0.696, 1.307)	0.942 (0.676, 1.313)
Maintain	Ref	Ref	Ref
Low increase	0.710 (0.531, 0.949)*	0.693 (0.518, 0.926)*	0.691 (0.516, 0.925)*
High increase	0.875 (0.580, 1.320)	0.849 (0.545, 1.322)	0.841 (0.536, 1.318)
P-trend	0.77	0.95	0.86

[1] Values are ORs (95% CIs); $n = 4734$. Model 1 was the crude unadjusted model. Model 2 adjusted for age in 2006, sex, baseline income (tertiles), education, geographic region, baseline urbanicity index (tertiles), baseline physical activity (tertiles), and smoking status. Model 3 additionally adjusted for baseline energy intake, baseline score tertile (only for annual change in tAHEI score), and baseline BMI. Baseline tAHEI scores are categorized into tertiles (low, medium, and high), with ''low'' as the reference group. Annual changes in tAHEI score are categorized into 5 levels, with ''maintain'' as the reference group. *P*-trend was calculated by assigning median values to each category of baseline score and annual changes in tAHEI scores, respectively, and entered as continuous terms in the models. $*P < 0.05$. CHNS, China Health and Nutrition Survey; HbA1c, glycated hemoglobin; Ref, reference; tAHEI, tailored Alternative Healthy Eating Index.

changes in diet quality considering its distribution. However, the gap between the cutoffs was narrow due to relatively small changes in the tAHEI score over time. Fourth, we calculated the tAHEI scores on the basis of 3 self-reported consecutive 24-h dietary recalls, which may have limited the adjustment for within-subject variation, especially for episodically consumed foods.

In conclusion, baseline and annual changes in diet quality were independently associated with lower HOMA-IR and insulin but were not related to fasting blood glucose and HbA1c in Chinese adults. Annual changes in diet quality were inversely associated with the risk of diabetes defined by fasting blood glucose. Our findings suggest that early intervention and a large improvement in diet quality may play key roles in improving insulin resistance. Studies on prospective associations between overall diet quality and longitudinal diabetes markers and incident diabetes are needed.

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References

1. Pan XR, Yang WY, Li GW, Liu J; National Diabetes Prevention and Control Cooperative Group. Prevalence of diabetes and its risk factors in China, 1994. Diabetes Care 1997;20:1664–9.
2. Yang W, Lu J, Weng J, Jia W, Ji L, Xiao J, Shan Z, Liu J, Tian H, Ji Q, et al. Prevalence of diabetes among men and women in China. N Engl J Med 2010;362:1090–101.
3. Chinese Diabetes Society, Chinese Medical Association. Guidelines for prevention and treatment of diabetes in China. Chin J Diabetes Mellitus 2014;6:447–98.
4. Cao XY, Zhou MG, Li YC, Wang LJ, Liu SW, Liu WN, Yin P, Liu JM, You JL. Disease burden of diabetes in China during 1990 and 2010. Chin J Prev Contr Chron Dis. 2015;23:904–7.
5. WHO. Global status report on noncommunicable diseases 2010. Geneva (Switzerland): WHO; 2011.
6. Zhai FY, Du SF, Wang ZH, Zhang JG, Du WW, Popkin BM. Dynamics of the Chinese diet and the role of urbanicity, 1991-2011. Obes Rev 2014;15(Suppl 1):16–26.
7. Popkin BM. Synthesis and implications: China's nutrition transition in the context of changes across other low- and middle-income countries. Obes Rev 2014;15(Suppl 1):60–7.
8. Ng SW, Norton EC, Popkin BM. Why have physical activity levels declined among Chinese adults? Findings from the 1991-2006 China Health and Nutrition Surveys. Soc Sci Med 2009;68:1305–14.
9. Dai Z, Butler LM, van Dam RM, Ang LW, Yuan JM, Koh WP. Adherence to a vegetable-fruit-soy dietary pattern or the Alternative Healthy Eating Index is associated with lower hip fracture risk among Singapore Chinese. J Nutr 2014;144:511–8.

10. Xiao YT, Su C, Ouyang YF, Zhang B. Trends of vegetables and fruits consumption among Chinese adults aged 18 to 44 years old from 1991 to 2011. Zhonghua Liu Xing Bing Xue Za Zhi 2015;36:232–6.
11. Hu FB. Dietary pattern analysis: a new direction in nutritional epidemiology. Curr Opin Lipidol 2002;13:3–9.
12. Willett WC. Eat, drink, and be healthy: the Harvard Medical School guide to healthy eating. New York: Free Press; 2005.
13. Harvard School of Public Health. The long road to the 2010 Dietary Guidelines for Americans [Internet]. 2010 [cited 2015 Sep 22]. Available from: http://www.hsph.harvard.edu/nutritionsource/dietary-guidelines-for-americans-2010/.
14. Willett WC, Stampfer MJ. Current evidence on healthy eating. Annu Rev Public Health 2013;34:77–95.
15. Chiuve SE, Fung TT, Rimm EB, Hu FB, McCullough ML, Wang M, Stampfer MJ, Willett WC. Alternative dietary indices both strongly predict risk of chronic disease. J Nutr 2012;142:1009–18.
16. de Koning L, Chiuve SE, Fung TT, Willett WC, Rimm EB, Hu FB. Diet-quality scores and the risk of type 2 diabetes in men. Diabetes Care 2011;34:1150–6.
17. Jacobs S, Harmon BE, Boushey CJ, Morimoto Y, Wilkens LR, Le Marchand L, Kröger J, Schulze MB, Kolonel LN, Maskarinec G. A priori-defined diet quality indexes and risk of type 2 diabetes: the Multiethnic Cohort. Diabetologia 2015;58:98–112.
18. Wang Z, Gordonlarsen P, Siegariz AM, Cai J, Wang H, Adair LS, Popkin BM. Sociodemographic disparity in the diet quality transition among Chinese adults from 1991 to 2011. Eur J Clin Nutr 2017;71:486–93.
19. Popkin BM, Du S, Zhai F, Zhang B. Cohort profile: the China Health and Nutrition Survey–monitoring and understanding socio-economic and health change in China, 1989-2011. Int J Epidemiol 2010;39:1435–40.
20. Moeller SM, Reedy J, Millen AE, Dixon LB, Newby PK, Tucker KL, Krebs-Smith SM, Guenther PM. Dietary patterns: challenges and opportunities in dietary patterns research an Experimental Biology workshop, April 1, 2006. J Am Diet Assoc 2007;107:1233–9.
21. Wang ZH, Zhang B, Wang HJ, Zhang JG, Du WW, Su C, Zhang J, Zhai FY. Study on the multilevel and longitudinal association between red meat consumption and changes in body mass index, body weight and risk of incident overweight among Chinese adults. Zhonghua Liu Xing Bing Xue Za Zhi 2013;34:661–7.
22. Tee ES. Development and promotion of Malaysian dietary guidelines. Asia Pac J Clin Nutr 2011;20:455–61.
23. Popkin BM, Lu B, Zhai F. Understanding the nutrition transition: measuring rapid dietary changes in transitional countries. Public Health Nutr 2002;5:947–53.
24. Ng SW, Howard A-G, Wang HJ, Su C, Zhang B. The physical activity transition among adults in China: 1991-2011. Obes Rev 2014;15(Suppl 1):27–36.
25. Ahuja J, Montville J, Omolewa TG, Heendeniya K, Martin C, Steinfeldt L, Anand J, Adler M, LaComb R, Moshfegh A. USDA Food and Nutrient Database for Dietary Studies, 5.0. USDA [Internet]. 2014. [cited 2017 Jun 25]. Available from: http://www.ars.usda.gov/ba/bhnrc/fsrg.
26. USDA Agricultural Research Service. USDA National Nutrient Database for Standard Reference, release 25 [Internet]. 2014 Nutrient Data Laboratory Home Page. [cited 2017 Jun 25]. Available from: http://www.ars.usda.gov/ba/bhnrc/ndl.
27. Jones-Smith JC, Popkin BM. Understanding community context and adult health changes in China: development of an urbanicity scale. Soc Sci Med 2010;71:1436–46.
28. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR Jr., Schmitz KH, Emplaincourt PO, et al. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc 2000;32:S498–504.
29. Fretts AM, Howard BV, McKnight B, Duncan GE, Beresford SA, Mete M, Eilat-Adar S, Zhang Y, Siscovick DS. Associations of processed meat and unprocessed red meat intake with incident diabetes: the Strong Heart Family Study. Am J Clin Nutr 2012;95:752–8.
30. Kourlaba G, Panagiotakos D. The number of index components affects the diagnostic accuracy of a diet quality index: the role of intracorrelation and intercorrelation structure of the components. Ann Epidemiol 2009;19:692–700.
31. Wang L, Gao P, Zhang M, Huang Z, Zhang D, Deng Q, Li Y, Zhao Z, Qin X, Jin D, et al. Prevalence and ethnic pattern of diabetes and prediabetes in China in 2013. JAMA 2017;317:2515–23.
32. Qin Y, Wang R, Ma X, Zhao Y, Lu J, Wu C, He J. Prevalence, awareness, treatment and control of diabetes mellitus—a population based study in Shanghai, China. Int J Environ Res Public Health 2016;13:E512.