Sociodemographic disparity in the diet quality transition among Chinese adults from 1991 to 2011

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BACKGROUND/OBJECTIVES: This study investigates secular trends in diet quality distribution and related socioeconomic disparity from 1991 to 2011 in the Chinese adult population.

SUBJECTS/METHODS: The analysis uses the 1991–2011 China Health and Nutrition Survey data on 13 853 participants (6876 men and 6977 women) aged 18–65 with 56 319 responses. Dietary assessment was carried out over a 3-day period with 24-h recalls combined with a household food inventory. We tailored Alternative Healthy Eating Index 2010 (named as tAHEI) to measure diet quality and performed quantile regression to investigate shifts in tAHEI scores at different percentiles and used mixed-effect linear regression to examine average diet quality trend and potential sociodemographic disparity.

RESULTS: The energy-adjusted mean tAHEI scores increased from 36.9 (36.7–37.1) points in 1991 to 50.3 (50.1–50.5) in 2011 for men ($P < 0.001$) and from 35.6 (35.4–35.8) to 46.9 (46.7–47.1) for women ($P < 0.001$). The covariate-adjusted score of polyunsaturated fatty acids increased by 6.8 (6.6, 7.0) and 7.0 (6.9, 7.2), and the score of long-chain (ω-3) fats increased by 5.3 (5.2, 5.4) and 5.3 (5.2, 5.5) in men and women, respectively, whereas the cereal fiber and red meat scores decreased slightly. Increasing tAHEI score occurred across the entire distribution, and diet quality transition varied across sociodemographic groups.

CONCLUSIONS: Chinese diet quality is far from optimal, with moderate improvement over a 21-year period. Findings suggest that nutritional intervention should give priority to low-income, low-urbanized communities and southern provincial adults with low diet quality in China.

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INTRODUCTION

The World Health Organization reports that unhealthy diet, excessive alcohol consumption, smoking and decreased physical activity (PA) are modifiable risk factors for the increasing chronic disease epidemic worldwide.[1] Over the past two decades, China has experienced marked shifts in diet[2,3] along with its rapid economic growth and social changes and the concurrent shifts in disease patterns.[3] Chinese food consumption has been characterized as rapid declines in intake of coarse grains, vegetables and legumes and increases in intake of edible oils and animal-source foods.[2–4] One key issue is how to capture the dynamic complexity of multidimensional diet changes.

Diet quality indexes, based on current healthy diet recommendations, have gained increasing attention for assessing diet quality as a whole and allowing for standardization of the scores, reproducibility of results and, thus, comparability of results across studies from different populations. The Harvard Healthy Eating Pyramid (HEP), a popular healthy diet guideline, is based on global scientific evidence on diet–disease relationships.[1,5,6] The Alternative Healthy Eating Index (AHEI)[7] and its most recent version AHEI-2010[8] assess adherence to the HEP and have strongly predicted major chronic disease risk in many Western populations.[9–13] Two recent studies showed the negative associaton of the AHEI with a risk of total mortality in Chinese adults[14] and hip fracture risk among Singapore Chinese,[15] which indicated the potential of the AHEI 2010 to access Chinese diet quality in terms of validated health benefit.

One recent study showed poor diet quality with a steady improvement in diet quality, assessed by AHEI-2010 scores, among the US population between 1999 and 2010.[16] To date, no study has investigated long-term trends in index-based diet quality and related sociodemographic characteristics in China.

The present study aimed to examine the long-term Chinese diet quality transition and the role that sociodemographic characteristics have in the transition. We therefore applied the tAHEI to assess overall diet quality and used longitudinal quantile regression to estimate trends in percentiles of diet quality and socioeconomic influence among adults aged 18–65 in China from 1991 to 2011 of the China Health and Nutrition Survey (CHNS).

SUBJECTS AND METHODS

Study population

All data used in this study were derived from the CHNS, an ongoing longitudinal study. Initiated in 1989, it focuses on assessing the relationships between the social and economic transformation in China and the resulting effects on the health and nutritional status of the Chinese population.[9,17] The CHNS used a multistage, random cluster process to draw the sample from eight provinces, and then 24 communities in each province were selected randomly as the primary sampling units. In each type of community, 20 households were randomly selected, and all

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Table 1. Cross-sectional characteristics of the study sample in the CHNS, 1991–2011

	Men								*Women*							
	1991	*1993*	*1997*	*2000*	*2004*	*2006*	*2009*	*2011*	*1991*	*1993*	*1997*	*2000*	*2004*	*2006*	*2009*	*2011*
N	3210	3473	3608	3998	3578	3496	3493	3063	3342	3581	3530	3967	3632	3634	3544	3170
Energy-adjusted tAHEI score[a,b]	36.9 ± 0.2	39.3 ± 0.2	39.0 ± 0.2	38.8 ± 0.2	40.4 ± 0.2	41.6 ± 0.2	42.1 ± 0.2	50.3 ± 0.2	35.6 ± 0.2	36.7 ± 0.1	35.9 ± 0.2	35.2 ± 0.1	36.4 ± 0.1	37.6 ± 0.1	38.2 ± 0.2	46.9 ± 0.2
Age (years)[a,b]	38.0 ± 0.2	37.2 ± 0.2	36.1 ± 0.2	35.4 ± 0.2	35.5 ± 0.2	35.3 ± 0.2	34.7 ± 0.2	34.7 ± 0.2	38.3 ± 0.2	37.7 ± 0.2	37.2 ± 0.2	36.4 ± 0.2	36.3 ± 0.2	35.9 ± 0.2	36.0 ± 0.2	36.0 ± 0.2
Income tertile[c,b]																
Low	1180.2	1188.5	1538.2	1617.9	1869.9	2172.3	3560.2	4346.2	1213.5	1188.2	1536.6	1651.1	1858.6	2014.7	3386.2	3834.3
Medium	2659.6	2785.5	3472.7	4339.3	5235.9	6081.4	9000.6	11341.1	2666.3	2785.1	3499.0	4461.4	5178.2	5856.5	8820.5	10678.7
High	4798.5	5689.9	6808.0	8679.0	12248.5	14353.9	19872.6	24033.5	4757.9	5763.0	6901.2	8810.2	12131.5	13982.2	19786.4	22687.7
Education (%)[b]																
Less than primary school	18.9	19.4	16.2	11.7	8.9	11.5	10.1	10.3	40.5	40.0	39.0	29.2	25.5	27.1	24.2	24.3
Primary school	21.5	23.6	23.5	23.0	22.7	18.8	19.9	19.2	18.5	20.5	21.2	23.3	24.3	19.7	22.4	22.3
Higher than primary school	59.6	57.0	60.3	65.3	68.4	69.8	70.0	70.5	41.0	39.5	39.8	47.5	50.2	53.2	53.4	53.4
Urbanicity tertile[c,b]																
Low	28.8	29.2	31.5	38.0	39.8	40.3	46.5	48.2	28.8	29.3	31.7	40.3	39.9	40.3	46.6	48.2
Medium	44.1	46.8	50.6	53.8	57.8	61.8	63.0	68.0	44.5	46.9	51.3	55.7	59.0	61.9	63.1	68.0
High	63.2	66.2	72.3	79.2	84.2	86.0	89.3	91.0	63.9	66.5	72.8	79.7	85.0	86.0	89.5	91.0
Geographic region (%)[b]																
Northern	13.3	12.0	5.0	20.3	21.1	22.2	21.5	23.0	12.8	11.8	4.8	21.0	22.9	22.2	22.5	23.9
Central	36.6	36.0	38.3	33.8	32.0	32.3	32.6	31.7	40.6	37.5	41.1	34.5	32.8	33.9	33.3	31.5
Southern	50.2	52.0	56.7	45.9	46.9	45.5	45.9	45.3	46.6	50.7	54.1	44.5	44.3	43.8	44.2	44.6

[a]Mean ± standard error. [b]Statistically significant difference among survey years based on χ^2 tests, analysis of variance tests or nonparametric median test for median of tertiles, $P < 0.05$. [c]Median values by survey-year-specific tertiles.

individuals in each household were surveyed for all data in each wave. The sampling procedure has been described in detail elsewhere.[5,17]

The CHNS has completed nine rounds (1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009 and 2011). We used data from 1991 to 2011, because only adults aged 20–45 years were involved in 1989. Of all 18- to 65-year-old participants who had complete socioeconomic and dietary data, we excluded women who were currently pregnant or lactating during a survey year and those having implausible energy intakes (< 800 kcal/day or > 6000 kcal for men and < 600 kcal or > 4000 kcal for women).[18] We also excluded participants with only one wave of data. Our final sample included 13 853 participants (6876 men and 6977 women) clustered in 234 communities with an average of 4.1 responses from each subject (56 319 responses).

The protocols of the survey were approved by the institutional review committees of the University of North Carolina at Chapel Hill and the National Institute of Nutrition and Food Safety, Chinese Center for Disease Control and Prevention. All subjects provided written informed consent for their participation in the protocols.

Assessment of diet quality

Dietary intake was assessed by collecting three consecutive 24-h dietary recalls (2 weekdays and 1 weekend day) for each individual combined with a household weighing inventory of all available foods over the same three periods and an interviewer-administered past-year food frequency questionnaire of sugar-sweetened beverages (SSB) and fruit juices since 2004 and alcohol consumption since 1993. The dietary data collection details have been described elsewhere.[19,20]

We used the tAHEI, tailored from the Harvard AHEI-2010,[8] to assess diet quality. The tailoring methods are described in detail elsewhere.[14] In general, major tailoring includes the following: (1) change in scale from serving to grams for vegetables, whole fruits, nuts and legumes, red/processed meat, SSBs and fruits juices; (2) estimation of alcohol and SSB and fruit juice intake from the past-year food frequency questionnaire in available survey years to reduce the potential underestimation of 24-h recall because of episodic consumption; (3) replacement of the whole-grain component with cereal fiber component because of 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 (about 3.1% of total meat) and few adults consumed processed meat higher than 64 g;[21] (5) linking all Chinese foods to the US Food and Drug Administration (USDA) Food and Nutrient Database for Dietary Studies (FNDDS)[22] and National Nutrient Database for Standard Reference[23] to estimate polyunsaturated fatty acid (PUFA) and long-chain (ω-3) fatty acid intake; and (6) omission of *trans*-fat component in the tAHEI given a lack of information on *trans*-fat composition of all eaten food in both China and USDA food composition tables (FCT). Supplementary Table 1 illustrates the components and scaling methods of the tAHEI. We used the 3-day average intakes of total energy, nutrients and foods and food groups to calculate total tAHEI scores ranging from 0 to 100. A higher score indicates a better diet quality and a score of 100 points indicates optimal diet quality.

Assessment of sociodemographic factors

Trained interviewers used standard questionnaires to collect information on household and individual incomes, individual education levels and community environments. We calculated per capita annual family income by dividing annual family income by household size in each survey, inflated the income to 2011 values by adjusting for the consumer price index and then categorized incomes as wave-specific tertiles. We grouped individual education levels into less than primary school, primary school and higher than primary school.

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.[24] We categorized the continuous urbanicity index into wave-specific tertiles. We also included the geographic regions (northern,

Table 2. Coefficients (95% CI) from quantile regression versus mixed-effect regression of the tAHEI score on survey year and socioeconomic factors in Chinese men

	Mean regression,[a] coefficient (95% CI)	*Quantile regression, coefficient (95% CI)*				
	Mean	*25th*	*50th*	*75th*	*85th*	*95th*
Model 1						
1993	2.3 (1.8, 2.7)***	1.7 (1.2, 2.1)***	2.2 (1.8, 2.6)***	2.9 (2.5, 3.4)***	3.2 (2.6, 3.9)***	3.2 (2.3, 4.0)***
1997	2.2 (1.8, 2.7)***	2.2 (1.8, 2.7)***	2.2 (1.7, 2.6)***	2.6 (2.2, 3.1)***	3.0 (2.5, 3.5)***	3.0 (1.8, 4.2)***
2000	1.8 (1.3,2.2)***	1.4 (1.0,1.8) ***	1.7 (1.3, 2.1)***	2.5 (2.0, 2.9)***	3.0 (2.5, 3.6)***	3.7 (2.8, 4.6)***
2004	3.3 (2.9, 3.8)***	2.2 (1.7, 2.7)***	3.0 (2.6, 3.4)***	4.7 (4.1, 5.3) ***	6.3 (5.6, 6.9)***	6.2 (5.1, 7.3)***
2006	4.7 (4.2, 5.1)***	2.9 (2.4, 3.5)***	4.3 (3.7, 4.9)***	6.4 (5.7, 7.0)***	7.9 (7.2, 8.7)***	9.2 (7.8, 10.6)***
2009	4.9 (4.5, 5.4)***	2.6 (2.1, 3.0)***	4.4 (3.9, 4.9)***	7.5 (6.9, 8.2)***	9.6 (8.8, 10.3)***	10.4 (8.9, 11.9)***
2011	13.1 (12.7, 13.6)***	11.1 (10.5, 11.8)***	14.6 (13.9, 15.2)***	17.5 (16.8, 18.2)***	18.7 (17.7, 19.7)***	19.0 (17.8, 20.2)***
Model 2						
1993	2.3 (1.8, 2.7)***	2.3 (0.8, 3.8)***	2.2 (1.8, 2.7)***	3.0 (2.3, 3.6)***	3.4 (2.9, 4.0)***	3.4 (2.6, 4.3)***
1997	2.2 (1.8, 2.7)***	2.7 (1.2, 4.2)***	2.2 (1.8, 2.6)***	2.7 (2.1, 3.2)***	3.2 (2.6, 3.8)***	3.1 (2.2, 4.1)***
2000	1.8 (1.3, 2.2)***	2.1 (0.6, 3.5)***	1.7 (1.3, 2.1)***	2.5 (2.0, 3.0)***	3.3 (2.7, 3.9)***	3.9 (2.9, 5.0)***
2004	3.4 (2.9, 3.8)***	3.2 (1.7, 4.8)***	3.1 (2.6, 3.6)***	4.9 (4.3, 5.4)***	6.5 (5.8, 7.1)***	6.4 (5.5,7.3)***
2006	4.7 (4.2, 5.1)***	3.9 (2.3, 5.5)***	4.3 (3.7, 4.8)***	6.6 (5.9, 7.2)***	8.2 (7.5, 9.0)***	9.7 (8.1, 11.2)***
2009	5.0 (4.5, 5.4)***	3.5 (1.9, 5.1)***	4.4 (3.7, 5.0)***	7.7 (6.9, 8.4)***	9.8 (9.0, 10.6)***	10.5 (9.2, 11.9)***
2011	13.1 (12.7, 13.6)***	12.1 (10.2, 13.9)***	14.6 (14.1, 15.1)***	17.6 (17.0, 18.2)***	18.9 (18.2,19.7)***	19.3 (18.2, 20.4)***
Model 3						
1993	2.3 (1.8, 2.7)***	1.7 (0.6, 2.8)***	2.2 (1.8, 2.6)***	3.1 (2.5, 3.7)***	3.3 (2.3, 4.4)***	2.9 (1.9, 3.8)***
1997	2.3 (1.8, 2.7)***	2.2 (1.0, 3.3)**	1.9 (1.5, 2.3)***	2.8 (2.3, 3.3)***	3.1 (2.1, 4.1)***	2.6 (1.5, 3.8)***
2000	1.8 (1.3, 2.2)***	1.3 (0.1, 2.4)*	1.4 (0.9, 1.8)***	2.5 (1.9, 3.1)***	2.9 (1.7, 4.1)***	3.1 (1.9, 4.3)***
2004	3.4 (2.9, 3.8)***	2.0 (0.7, 3.3)**	2.7 (2.2, 3.3)***	4.9 (4.2, 5.6)***	6.1 (5.0, 7.2)***	6.3 (4.7, 7.9)***
2006	4.7 (4.2, 5.1)***	2.9 (1.6, 4.2)***	4.0 (3.4, 4.5)***	6.4 (5.7, 7.0)***	7.6 (6.4, 8.9)***	8.9 (7.7, 10.1)***
2009	4.9 (4.5, 5.4)***	2.3 (1, 3.7)**	4.0 (3.5, 4.6)***	7.6 (7.0, 8.3)***	9.5 (8.3, 10.7)***	10.1 (8.6, 11.6)***
2011	13.1 (12.6, 13.6)***	10.9 (9.3, 12.6***	14.3 (13.8, 14.8)***	17.4 (16.7, 18)***	18.6 (17.6, 19.6)***	18.6 (17.4, 19.8)***

[a]Mixed-effect linear random intercept regression models.[b]Models adjusted for survey years (dummy variables) and baseline age (model 1), plus individual income (tertile) and education (less than primary, primary and higher than primary) (model 2), additional urbanicity index (tertile) and geographic region (model 3). $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

central and southern) because of the different dietary intakes shown in previous studies.[25,26]

Statistical analysis

We first present descriptive statistics (means and s.d.'s for continuous variables, and frequencies for categorical variables) on socioeconomic factors of interest stratified by sex for adults by survey years. We used χ^2 tests for categorical variables, analysis of variance tests for continuous variables and nonparametric median test for median of tertiles to test differences among survey years. For cross-sectional analysis, we first conducted a Kolmogorov–Smirnov test for normality and confirmed that the distribution for tAHEI is not normal. We then estimated the quantiles of the tAHEI scores based on simple frequencies. We also used LMS method (the L curve (Yeo–Johnson to remove skewness), M curve (median) and S curve (coefficient of variation))[27] to present graphically smoothing probability density distribution of the tAHEI scores for select waves of the CHNS.

Next, we used the longitudinal quantile regression method[28,29] to see whether secular trends and associations of diet quality vary at different percentiles of the tAHEI scores after adjustment for all potential covariates. For comparison, we also performed three-level (survey years (level 1) for individuals (level 2) nested in communities (level 3)) mixed-effect linear random intercept regression models[30] to estimate average secular trend of the total tAHEI scores and each component score, adjusting for all potential covariates including survey year, baseline age, income, education, urbanicity, geographic regions and total energy intake. We included baseline age as continuous and modeled survey years as dummy variables rather than continuous, given potentially uneven changes over time.

Last, we introduced statistically significant time–sociodemographic product terms (time–income, time–education, time–urbanicity and time–region) based on likelihood ratio test into linear mixed-effect model and used this fully adjusted model for predicted mean of tAHEI scores over time across sociodemographic subpopulations, respectively.

All statistical tests were two-tailed, and we regarded differences as significant at $P < 0.05$. We fitted three-level mixed-effect linear models using Stata/SE version 14.1, plotted density and quantile distribution using the VGAM package and performed quantile regression models using the LQMM package in R version 2.15.1. For all other descriptive analyses, we used SAS version 9.3.

RESULTS

As shown in Table 1, the energy-adjusted mean tAHEI scores and 95% confidence intervals (CI) increased from 36.9 (36.7–37.1) points in 1991 to 50.3 (50.1–50.5) points in 2011 for men ($P < 0.001$) and from 35.6 (35.4–35.8) to 46.9 (46.7–47.1) points for women ($P < 0.001$), both with bigger increases between 2009 and 2011 (men, 8.2; women, 12.5) than between other adjacent survey years. Moreover, distributions of education level and geographic region and mean baseline age were significantly different across survey years ($P < 0.05$). The median of each income and urbanicity index tertiles increased significantly over time ($P < 0.05$).

Shifts in the distribution of the unadjusted tAHEI scores in Chinese adults

Supplementary Table 2 presents mean and distribution (at the 10th, 25th, 50th, 75th, 90th and 95th percentiles) of the unadjusted tAHEI scores along with 95% CI from 1991 to 2011 for men and women, respectively. We can see that the degree of increase in unadjusted tAHEI score was uneven, with upper percentile score having a larger rate of increase than the lower percentile score. The increase in the 95th percentile from 1991 to 2011 was around 18.4 points in men and 14.8 points in women,

Table 3. Coefficients (95% CI) from quantile regression versus mixed-effect regression of the tAHEI score on survey year and socioeconomic factors in Chinese women

	Mean regression,[a] coefficient (95% CI)	*Quantile regression, coefficient (95% CI)*				
	Mean	*25th*	*50th*	*75th*	*85th*	*95th*
Model 1[b]						
1993	1.1 (0.7, 1.5)***	0.5 (0.1, 0.9)***	1.0 (0.7, 1.4)***	1.5 (1.1, 2.0)***	1.8 (1.3, 2.4)***	1.9 (1.3, 2.6)***
1997	0.5 (0.1, 0.9)*	0.1 (-0.4, 0.5)	0.1 (-0.3, 0.5)	0.5 (0.1, 0.9)*	0.7 (0.2, 1.3)**	1.5 (0.4, 2.6)**
2000	−0.5 (−0.9, −0.1)**	−0.9 (−1.3, −0.6)***	−0.8 (−1.2, −0.3)***	−0.4 (−0.8, 0)	−0.1 (−0.7, 0.4)	0.2 (−0.7, 1.0)
2004	0.6 (0.2, 1.0)**	−0.7 (−1.0, −0.3)***	0.1 (−0.4, 0.5)	1.4 (0.9, 1.9)***	2.8 (2.2, 3.5)***	3.3 (2.3, 4.4)***
2006	1.9 (1.5, 2.3)***	0 (−0.5, 0.5)	1.1 (0.5, 1.7)***	3.1 (2.5, 3.7)***	4.9 (4.2, 5.7)***	5.3 (4.2, 6.5)***
2009	2.3 (1.9, 2.7)***	−0.4 (−0.8, 0.1)	1.3 (0.8, 1.7)***	4.4 (3.7, 5.0)***	6.8 (6.0, 7.7)***	8.0 (6.6, 9.3)***
2011	10.7 (10.3, 11.2)***	8.4 (7.7, 9.0)***	12.3 (11.6, 12.9)***	14.8 (14.3, 15.4)***	16.1 (15.3, 17.0)***	16.2 (15.3, 17.1)***
Model 2						
1993	1.1 (0.7, 1.5)***	0.6 (−0.5, 1.7)	1.1 (0.8, 1.5)***	1.5 (1.1, 2)***	1.8 (1.3, 2.4)***	1.9 (1.2, 2.7)***
1997	0.5 (0.1, 0.9)*	0 (−1.2, 1.3)	0.2 (−0.1, 0.6)	0.5 (0, 1.0)*	0.7 (0.1, 1.4)*	1.5 (0.3, 2.6)*
2000	−0.5 (−0.9, −0.1)*	−0.8 (−2.0, 0.5)	−0.6 (−1.0, −0.2)**	−0.4 (−0.9, 0.1)	0 (−0.6, 0.7)	−0.1 (−1.1, 1.0)
2004	0.6 (0.2, 1.0)**	−0.4 (−1.8, 0.9)	0.4 (−0.1, 0.8)	1.5 (0.9, 2.0)***	2.9 (2.1, 3.6)***	3.2 (2.2, 4.1)***
2006	1.9 (1.5, 2.3)***	0.1 (−1.2, 1.5)	1.2 (0.8, 1.7)***	3.2 (2.5, 3.8)***	4.9 (4.1, 5.8)***	5.3 (3.8, 6.9)***
2009	2.4 (2.0, 2.8)***	−0.2 (−1.4, 1.1)	1.4 (0.9, 1.8)***	4.6 (3.8, 5.4)***	7.0 (6.0, 8.0)***	8.0 (6.6, 9.3)***
2011	10.8 (10.3, 11.2)***	8.6 (7.0, 10.2)***	12.5 (12, 13)***	14.9 (14.3, 15.5)***	16.1 (15.2, 16.9)***	16.3 (15.3, 17.4)***
Model 3						
1993	1.1 (0.7, 1.5)***	1.5 (0.6, 2.5)**	1.0 (0.6, 1.5)***	1.7 (1.2, 2.2)***	1.6 (1.0, 2.3)***	1.8 (0.5, 3.0)***
1997	0.5 (0.1, 0.9)*	1.2 (0.1, 2.2)*	0.3 (−0.2, 0.7)	0.6 (0, 1.1)*	0.7 (0.1, 1.4)*	1.4 (0.3, 2.5)*
2000	−0.5 (−0.9, −0.1)**	0 (−1, 0.9)	−0.7 (−1.1, −0.4)	−0.4 (−0.8, 0.1)	−0.3 (−0.9, 0.3)	0.3 (−0.8, 1.4)
2004	0.6 (0.2, 1.0)**	0.3 (−0.8, 1.4)	0.1 (−0.3, 0.5)***	1.6 (1.1, 2.2)***	2.5 (1.8, 3.1)***	4.1 (2.8, 5.4)***
2006	1.9 (1.5, 2.3)***	1.0 (−0.1, 2.2)	1.2 (0.8, 1.6)***	3.3 (2.7, 3.9)***	4.6 (4.0, 5.3)***	5.2 (3.6, 6.8)***
2009	2.3 (1.9, 2.8)***	0.8 (−0.3, 1.9)	1.2 (0.7, 1.7)***	4.5 (3.8, 5.2)***	6.6 (5.7, 7.6)***	8.0 (6.4, 9.6)***
2011	10.8 (10.3, 11.2)***	9.8 (8.2, 11.3)	12.2 (11.7, 12.7)***	15.0 (14.5, 15.5)***	15.8 (15.1, 16.5)***	16.1 (14.8, 17.3)***

[a]Mixed-effect linear random intercept regression models. [b]Models adjusted for survey years (dummy variables) and baseline age (model 1), plus individual income (tertile) and education (less than primary, primary and higher than primary) (model 2), additional urbanicity index (tertile) and geographic region (model 3). *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

whereas the increase for the median was 13.6 and 11.6 and for the 10th percentile it was only 7.3 and 4.7, respectively.

We also show graphically the shifts in the distribution of the unadjusted tAHEI scores using LMS methods in men and women for selected survey years (Supplementary Figure 1). For both sexes the distribution generally shifts to the right, with the distributions becoming wider and flatter, with a larger proportion of the subjects having higher tAHEI scores over time. We also observed different degrees of shifts in the whole distribution over time. For men, the shift was gradually flattening over time, with slightly larger shifts between 2009 and 2011. In contrast, for women, there was a remarkable rightward shift and flattening only between 2006 and 2011, with no significant changes before 2006.

Secular trends in covariate-adjusted tAHEI score at different percentiles

As shown in Tables 2 and 3, increasing trends in the tAHEI score occurred at various percentiles for both sexes after adjustment for all potential covariates. We also observed gradually steeper rate of increase with increasing percentiles of the tAHEI score and remarkable upward jump between 2009 and 2011 at various percentiles. In addition, the median (50th percentile) estimates from quantile regression shows fairly steeper values than the mean estimate of secular trends for both sexes.

For men, after additional adjustment for income and education (model 2), only the 25th percentile estimates in 2011 as compared with 1991 attenuated by 1.0 point. After adjustment for urbanicity and geographic region (model 3), the 25th and the 95th percentile estimates in 2011 attenuated by 1.1 points and 0.7 points, respectively.

For women, the coefficients at various percentiles did not change significantly from adjustment for income and education in model 2. Then, only the 25th percentile estimates in 2011 attenuated by 0.8 points from additional adjustment from urbanicity and geographic region.

Secular trends in covariate-adjusted mean tAHEI component score

Figure 1 illustrates how tAHEI component scores changed over time. For both sexes, PUFAs, EPA and DHA scores showed the most remarkable increasing trends between 2009 and 2011. Compared with the scores in 1991, PUFAs and EPA plus DHA scores in 2011 increased by 6.8 points and 5.3 points in men and 7.0 points and 5.3 points in women, respectively. In contrast, the cereal fiber score, SSB score and red meat score showed slight declines for both sexes. In addition, whole fruits score and nuts and legumes score showed slight increases by about 1.0 points. Alcohol scores, on the other hand, increased by 2.3 points only among men over the 21-year period.

Table 4 presents predicted mean of the tAHEI score across demographic and socioeconomic factors from a fully adjusted mixed-effect linear regression. Figure 2 graphically illustrates potential disparity in tAHEI score transition. The increasing tAHEI score within northern adults indicated larger increase than that seen among southern adults, and the difference in tAHEI score between northern and southern adults increased significantly from 2.4 points in 1991 to 7.2 points in 2011 in men and from 1.8 points to 6.6 points in women. High urbanicity was associated with lower tAHEI score before 2004 but with higher diet quality after 2004 for both sexes given the slightly large increase in lower urbanicity adults over time. In addition, men with primary school had slightly higher scores than those with other corresponding groups in 2011, whereas tAHEI scores in women were not significantly different across income or education groups in 2011.

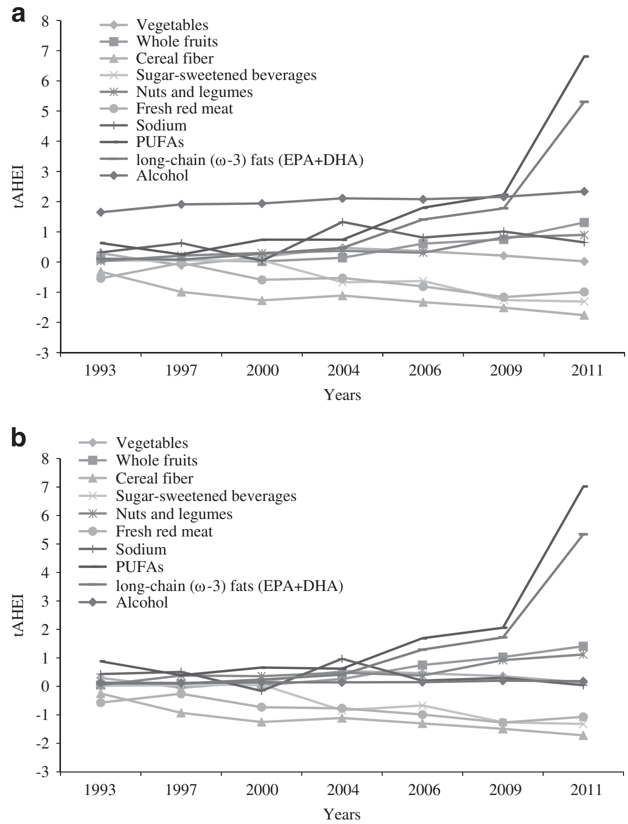

Figure 1. Estimated shifts in covariate-adjusted tAHEI component score in Chinese men (**a**) and women (**b**) in China, CHNS, 1991–2011 (estimation based on mixed-effect linear regression models adjustment for survey year, baseline age, income, education, geographic region, urbanicity and total energy intake).

DISCUSSION

Using data from the CHNS between 1991 and 2011, we found a moderate increase across the entire distribution of the tAHEI scores, with the most remarkable improvement between 2009 and 2011. Our study also showed that the diet quality transition varied greatly across score percentiles and that adults with higher percentile score tended to have larger increase than those with lower percentile score over time. Improvements in diet quality were mainly attributable to increased scores of PUFAs, EPA and DHA. In addition, improved diet quality was observed in all sociodemographic groups with significant sociodemographic disparity.

Limited studies have used the AHEI-2010 to assess diet quality and/or to examine longitudinal trends. One recent study in a nationally representative sample of 29 124 US adults aged 20–85 years indicated increased energy-adjusted AHEI-2010 scores without the *trans*-fat component from 34.2 (33.1–35.2) in 1999–2000 to 37.1 (36.6–37.7) in 2009–2010.[16] Increased scores in US adults mainly resulted from an increase of 0.9 points for SSB and fruit juice, 0.7 points for whole fruit, 0.5 points for whole grains and 0.4 points for nuts and legumes and slight decrease in sodium.[16] Our study observed an increase of 11.3 points for Chinese men and women aged 18–65 years between 2000 and 2011. Chinese adults had better diet quality and gained larger improvement in diet quality than US adults in the past decade. Different from that in US adults, the changed profiles in Chinese adults were characterized by an increase of 7.0 points for PUFAs, 5.3 points for long-chain (ω-3) fatty acid score, 1.0 points for whole fruit and nuts and legume, as well as a slight decline in the scores

Table 4. Predicted tAHEI score by demographic and socioeconomic factors, CHNS, 1991–2011

Characteristic	*1991*	*1993*	*1997*	*2000*	*2004*	*2006*	*2009*	*2011*
Men[a]								
Income								
Low	37.0 (0.4)	40.0 (0.3)	40.0 (0.3)	39.0 (0.3)	41.1 (0.3)	42.2 (0.3)	41.8 (0.3)	49.7 (0.3)
Medium	37.1 (0.3)	39.6 (0.3)	39.1 (0.3)	39.0 (0.3)	40.8 (0.3)	41.9 (0.3)	42.2 (0.3)	50.8 (0.3)
High	36.8 (0.3)	38.6 (0.3)	38.8 (0.3)	38.7 (0.3)	39.9 (0.3)	40.9 (0.3)	42.7 (0.3)	50.2 (0.4)
Education								
Less than primary school	36.9 (0.4)	39.9 (0.4)	39.6 (0.4)	38.4 (0.5)	41.6 (0.6)	41.7 (0.5)	43.3 (0.5)	49.6 (0.6)
Primary school	37.1 (0.4)	40.1 (0.4)	39.3 (0.4)	38.6 (0.4)	40.3 (0.4)	41.1 (0.4)	42.4 (0.4)	51.0 (0.4)
Higher than primary school	37.0 (0.3)	39.1 (0.3)	39.2 (0.3)	39.1 (0.3)	40.6 (0.3)	41.9 (0.3)	42.0 (0.3)	50.1 (0.3)
Geographic region								
Northern	38.1 (0.6)	42.2 (0.6)	42.2 (0.6)	39.9 (0.5)	41.0 (0.5)	44.6 (0.5)	44.2 (0.5)	55.8 (0.5)
Central	38.3 (0.4)	40.8 (0.4)	40.8 (0.4)	40.7 (0.4)	41.5 (0.4)	43.6 (0.4)	43.5 (0.4)	49.7 (0.4)
Southern	35.7 (0.4)	37.3 (0.3)	37.1 (0.3)	37.2 (0.3)	39.9 (0.4)	39.2 (0.4)	40.6 (0.4)	48.6 (0.4)
Urbanicity								
Low	37.7 (0.4)	39.0 (0.4)	39.1 (0.4)	40.1 (0.3)	41.7 (0.4)	41.4 (0.4)	42.2 (0.4)	50.0 (0.4)
Medium	37.7 (0.4)	40.4 (0.3)	40.1 (0.3)	39.0 (0.3)	40.2 (0.3)	41.4 (0.3)	41.9 (0.3)	49.7 (0.4)
High	35.5 (0.4)	38.8 (0.4)	38.6 (0.4)	37.6 (0.3)	40.0 (0.4)	42.2 (0.4)	42.6 (0.4)	51.1 (0.4)
Women								
Income								
Low	35.9 (0.3)	37.3 (0.3)	36.7 (0.3)	35.6 (0.3)	36.9 (0.3)	38.1 (0.3)	38.2 (0.3)	46.4 (0.3)
Medium	35.6 (0.3)	37.0 (0.3)	36.1 (0.3)	35.3 (0.3)	37.1 (0.3)	37.4 (0.3)	38.5 (0.3)	47.1 (0.3)
High	35.2 (0.3)	36.0 (0.3)	35.8 (0.3)	35.2 (0.3)	36.1 (0.3)	37.5 (0.3)	38.6 (0.3)	46.8 (0.3)
Education								
Less than primary school	35.6 (0.3)	37.1 (0.3)	36.4 (0.3)	35.5 (0.3)	38.2 (0.3)	37.5 (0.3)	38.5 (0.3)	46.8 (0.4)
Primary school	36.0 (0.4)	36.7 (0.4)	35.8 (0.3)	34.8 (0.3)	36.1 (0.3)	37.5 (0.4)	38.7 (0.4)	46.6 (0.4)
Higher than primary school	35.4 (0.3)	36.6 (0.3)	36.2 (0.3)	35.5 (0.3)	36.1 (0.3)	37.9 (0.3)	38.3 (0.3)	46.8 (0.3)
Geographic region								
Northern	36.1 (0.6)	38.0 (0.6)	37.5 (0.6)	35.6 (0.5)	36.9 (0.5)	39.9 (0.5)	39.8 (0.5)	51.7 (0.5)
Central	36.9 (0.4)	38.4 (0.4)	38.1 (0.4)	37.1 (0.4)	37.3 (0.4)	39.2 (0.4)	39.7 (0.4)	46.4 (0.4)
Southern	34.3 (0.3)	35.0 (0.3)	34.1 (0.3)	33.9 (0.3)	36.2 (0.3)	35.6 (0.3)	36.9 (0.3)	45.1 (0.3)
Urbanicity								
Low	36.1 (0.4)	36.6 (0.3)	36.5 (0.3)	36.0 (0.3)	37.4 (0.3)	37.2 (0.3)	37.8 (0.3)	46.1 (0.3)
Medium	36.4 (0.3)	37.4 (0.3)	36.7 (0.3)	35.5 (0.3)	36.6 (0.3)	37.2 (0.3)	38.2 (0.3)	46.6 (0.3)
High	34.2 (0.3)	36.2 (0.3)	35.3 (0.3)	34.6 (0.3)	36.2 (0.3)	38.6 (0.3)	39.3 (0.3)	47.6 (0.3)

Abbreviations: CHNS, China Health and Nutrition Survey; tAHEI, tailored Alternative Healthy Eating Index. [a]Values are predicted margins (s.e.) estimated by mixed-effect linear random intercept models adjusted for baseline age (continuous), total energy intake (continuous), survey years (dummy variables), income, education, geographic region, urbanicity and corresponding interaction terms with survey years.

of cereal fiber, SSB and fruit juices and red meat over time. Significant increases in the intake of edible oils[2,31] and sea foods[2,32] in Chinese adults in the past two decades may be a possible explanation for great increase in PUFAs and EPA plus DHA score. However, such comparison should be understood with caution given that the tAHEI was not quite identical to AHEI-2010 because of tailoring.

Previous studies using the CHNS data examined the role of sociodemographic characteristics for changes in specific nutrients, foods or food groups in Chinese adults: positive association of income with intakes of animal-source foods,[31,33,34] edible oils[31,33,34] and percentage of energy from dietary fat[33,34] and negative association of income with cereal intake,[31] relationship of higher urbanicity with higher intake of total animal-source foods and lower intake of coarse grains in adults aged 18–59 years between 1991 and 2011.[2] Our results add valuable information on sociodemographic disparity in Chinese diet quality transition. We found wider gaps in diet quality between southern and northern adults over time, and lower diet quality in lower-urbanized adults since 2004. Income and education levels were not associated with women's diet quality, whereas gaps in diet quality across income or education in men narrowed. In contrast, Wang *et al.* found that US adults with higher socioeconomic status had greater improvement in diet quality, assessed by AHEI-2010, and the gaps in diet quality between higher and lower SES adults widen over a 12-year period.[16,35] One recent study using NHANES cycles (1999–2012) also showed that the disparities in the diet scores, constructed based on the AHA 2020 Strategic Impact Goals for diet, widen over time, with smaller overall improvements in those with lower levels of family income and lower education levels in US adults aged 20 years or older.[36]

Our study is the first to investigate 21-year trends in index-based diet quality distribution in a large longitudinal sample in a country undergoing rapid nutrition transitions. The use of tAHEI was an easier and more practical way to standardize and track diet quality transitions than research on specific nutrients, foods or food groups over time.[2,4,31,32,37] The longitudinal quantile regression and mixed-effect linear regression that we used are well suited for the repeated diet measure in the CHNS and best represent trends in diet quality distribution and transition. Both approaches have the ability to handle unbalanced panel data, insensitivity to outliers and provide more precise and robust estimates than ordinary least-square regressions. Moreover, quantile analysis can provide multiple estimates to reflect characteristics of diet quality transition across the whole distribution. Survey years modeled as dummy variables contribute to discovering the uneven degree of diet quality transition over time instead of a continuous coding presenting average changes per year.

Several limitations should be considered. First, the tailored tAHEI was not identical to the AHEI-2010 and may not reflect the nature of the AHEI-2010. For example, we may underestimate

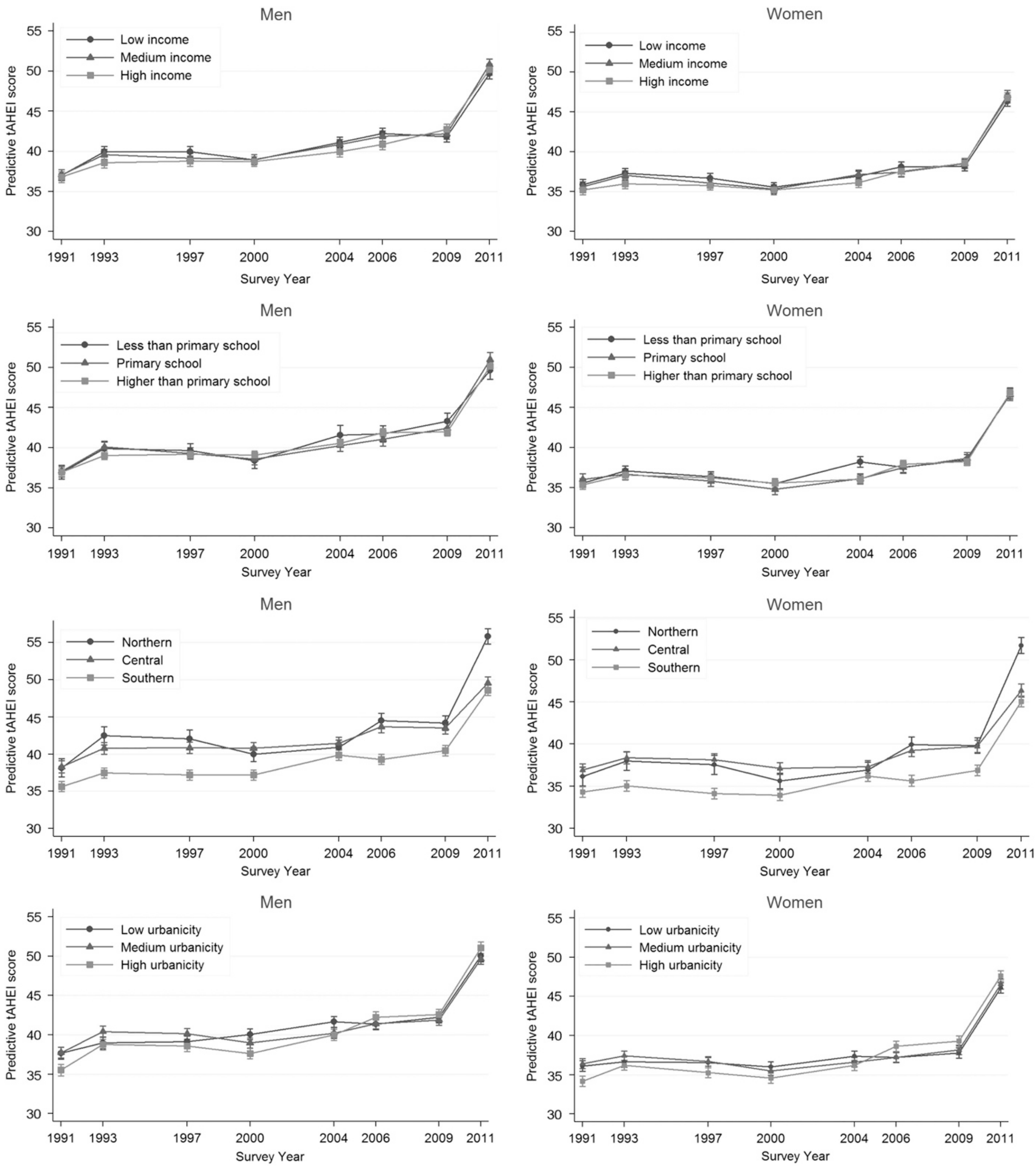

Figure 2. Predicted tAHEI score across demographic and socioeconomic factors in Chinese adults, CHNS, 1991–2011 (estimation based on mixed-effect linear regression models adjustment for baseline age, total energy intake, survey years, income, education, geographic region, urbanicity and corresponding interaction terms with survey years).

cereal fiber intake because of limited insoluble fiber in China FCT. Fatty acid composition may be different because of country-specific food types and planting conditions. We omitted a *trans*-fat component, but it was shown as one important dimension of the overall diet quality.[2,38,39] In addition, the tAHEI does not consider cooking methods or eating behaviors. Previous studies reported a marked increase in the proportion of energy from deep-fried and stir-fried foods and from snacking over time,[2,40] which may be an important aspect of overall diet quality in relation to disease risk.

In conclusion, Chinese adults gained moderate improvements in the overall quality across the whole distribution between 1991 and 2011. However, Chinese diet quality is still far from optimal (about 50.0 points out of 100 full points) with sociodemographic disparity. From the perspective of public health, web-based key technology of nutrition interventions and government-dominated policy efforts should be given priority to adults with low diet quality who generally had low income, lived in low-urbanized communities and lived in southern China.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHOR CONTRIBUTIONS

ZW designed and conducted the analysis and drafted the manuscript. PG-L, AMSR, JC, LA, HW and BP contributed to the interpretation of the data analysis and critical revision of the manuscript for important intellectual content. ZW and BP had full access to all of the data in the study and had primary responsibility for the final content.

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