DIET QUALITY TRANSITION OVER TIME AND ITS ASSOCIATION WITH CARDIOMETABOLIC RISKS AMONGADULTS IN CHINA

Zhihong Wang

A dissertation submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Nutrition in the Gillings School of Global Public Health.

Chapel Hill
2016

Approved by:

Barry M. Popkin

Linda Adair

Penny Gordon-Larsen

Anna Maria Siega-Riz

Jianwen Cai

ABSTRACT

Zhihong Wang: Dietary quality transition over time and its association with Cardiometabolic risks among adults in China
(Under the direction of Barry M. Popkin)

The expanding burden of obesity and associated cardiometabolic risk (CM) in Asian populations is of particular concern given their higher CM risk at lower BMI level and at younger ages relative to Western populations. An index-based diet quality approach is a useful way to capture the complex interplay of dietary constituents and fully investigate the overall diet - disease relationship. Many studies have shown that Alternative Healthy Eating Index-2010(AHEI-2010), created based on Harvard Healthy Eating Pyramid (HEP), were negatively associated with the risks of obesity, dyslipidemia, diabetes, some cancer and mortality in US and European population.

Using the panel data of China Health and Nutrition Survey from 1991 to 2011, we examined the association of index-based current diet quality (one time point of 2006 wave) or long-term diet quality trends (from 1991 to 2006) and cardiometabolic risks among adults aged 18 to 65 in China.

In Aim 1, we used Chinese dietary guidelines to create the China dietary quality index (CDQI) and tailored the AHEI-2010 to match the Chinese diet (named as tAHEI). Then we examined the association between the CDQI and tAHEI score in 2006 with risk of diabetes and major CM risks in 2009. We found that the CDQI and tAHEI score showed similarly negative associations with risk of low density lipoprotein cholesterol (LDL-C), whereas the CDQI score was positively associated with elevated triacylglycerol risk in women. Aim 2 investigated socioeconomic disparity in 20-year diet quality transition. Results indicated that the past two decades brought moderate improvement in overall diet quality across the entire distribution, with greater improvement in those starting with better diet quality. In Aim 3 we evaluated the association of 15-year diet quality trends with diabetes biomarkers in 2009. High baseline score and high increase in the score were independently associated with lower Homeostasis Model of Insulin Resistance (HOMA-IR) and insulin but not related to fasting glucose, hemoglobin A1c and defined diabetes with certain exception.

In conclusion, our findings suggest that diet consistent with Harvard HEP had beneficial impact on improving insulin resistance and LDL-C. Future nutrition intervention and policy should give priority to adults with poor diet quality who generally have lower incomes and live in lower urbanized communities or southern China.

ACKNOWLEDGEMENTS

This work would not have been possible without the valuable input and great support of many people.

To my advisor, Barry Popkin. Without him, I would not have this valuable opportunity pursuing a PhD program in the top division of nutrition epidemiology worldwide. He have checked through my dissertation with patience and given me instructive suggestions. Without his insightful guidance and persistent help, I would not finish the research. I'll never forget his warm hug and thoughtful encouragement when I felt frustrated and stressful. He also plays an important role in indicating a bright road in my professional career. I am so proud of being his student.

To my committee members, Linda Adair, Penny Gordon-Larsen, Anna Maria Siega-Riz, and Jianwen Cai. Special thanks to them. They have contributed their precious time and valuable expertise to my research. Without their encouragement, thoughtful consideration and great support to me, my dissertation would not have been possible. I am extremely honored of having them as my committee members.

To Shufa Du, Guifeng Jin, Phil Bardsley, Shuwen Ng, Michelle A. Mendez, Fei Dong, Bonnie Qin, Qi Ning, Zhaohui Cui, Pengcheng Xun, Xiaofan Zhang and Xiao Zhang. They give me generous supports and helpful advices in my data analyses, defense presentation and dissertation writing-up.

To all the Nutrition and Epidemiology professors and students I interacted with. They carefully designed their courses and helped me understand the basic concepts, learn theoretical application and practice, and hone high-level skills in nutritional epidemiology. I especially thank my nutritional epidemiology cohort *Elizabeth, Carolina, Carmen and Niha.*

They are easygoing, hardworking and caring. They gave me great help, thoughtful encouragement and valuable advice in my PhD study. I enjoyed wonderful time studying with them at UNC.

To my directors and all my colleagues in National Institute for Nutrition and Health, Fengying Zhai, Bing Zhang, Gangqiang Ding, Weixing Yan, Huijun Wang, Jiguo Zhang, Wenwen Du, Chang Su, Ji Zhang, Hongru Jiang, Feifei Huang, Xiaofang Jia, Yifei Ouyang and others. Without their great supports, thoughtful understanding and warm accompanying, I would not finally succeed in my PhD study.

To my best friends, Ailing Liu, Zhenyu Yang, Deqian Mao, Yan Li, Xia Xu, Yuanyuan Zhang and others. I enjoyed happy time of delicious foods, coffee flavor, and romantic music with them. I treasure our friendship.

To my parents, my older brother, my husband and my lovely daughter. I am immensely grateful to them. They have been a constant source of love, concern, support and strength all these years. My father got a stroke in 2010 when I studied at UNC and has been paralyzed these years. My mother and older brother did not tell me the truth because they were worried of my heavy learning tasks. My husband transferred his PhD program to the UNC and my family stayed together and enjoyed the good time of happy life and study. Special thanks to my daughter, she has always accompanied me for support these years, even giving up her own study with the teachers and best friends that she likes in Beijing. The lovely girl is the love of my life.

I also thank the funding source, the Fogarty NIH grant that have made my studies possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

AHEI	Alternative healthy eating index
BMI	Body Mass Index
CDG	Chinese dietary guidelines
CM	Cardiometabolic
CVD	Cardiovascular diseases
CHNS	China Health and Nutrition Survey
CI	confidence interval
DG	Dietary guidelines
DGA	Dietary guidelines for American
DGC	Dietary guidelines for Chinese
DHA	docosahexenoic acid
DQI	Diet Quality Index
EPA	eicosapntemacnioc acid
FCT	food composition table
FFQ	Food Frequency Questionnaires
FNDDS	Food and Nutrient Database for Dietary Studies
HbA1c	Hemoglobin A1c
HDL	High-density Lipoprotein
HEI	Healthy eating index
HEP	Healthy Eating Pyramid
HOMA-IR	Homeostasis Model of Insulin Resistance
LDL-C	low-density lipoprotein cholesterol
NIH	National Institutes of Health
NINF	National Institute of Nutrition and Health

NNDSR	National Nutrient Database for Standard Reference
PA	physical activity
PUFA	polyunsaturated fatty acid
SES	socioeconomic status
SSB	sugar-sweetened beverage
TG	Triglyceride
tAHEI	tailored Alternative Healthy Eating Index
UNC-CH	University of North Carolina at Chapel Hill
USDA	US Department of Agriculture

CHAPTER 1: INTRODUCTION

Background

The rising epidemic of obesity, diabetes and associated cardiometabolic (CM) risks have been public health concerns worldwide in the past decades. This is especially pertinent for Asian countries given that these settings have faced very rapid socioeconomic and nutrition transitions and Asians tend to have higher CM risks at lower BMI level and at younger ages relative to the Western populations. It was shown that approximately 85% of Chinese adults aged 40 years and older, and 33.2% of non-overweight Chinese adults had high levels of at least one CM risk factor in 2009. The prevalence of diabetes in Chinese adults was 0.67% in 1984, 2.5% in 1994, and 9.7% in 2010 among adults in China. The diabetes mortality and disability adjusted life years between 1990 and 2000 increased by 45.0% and 10.3%, respectively. To curb the rising epidemic and disease burden, effective actions call for evidence-informed, scientifically evaluated strategies and policies.

Diet has been playing a key role in preventing chronic diseased epidemics. Index-based diet quality approach is a useful way to capture the complex interplay of dietary constituents and fully investigate the overall diet - disease relationship. Many studies have shown that Alternative Healthy Eating Index-2010 (AHEI-2010), created based on Harvard Healthy Eating Pyramid (HEP), has the potentially beneficial effect of lowering risk of obesity, dyslipidemia, diabetes, some cancer and mortality in many Western populations. However, it remains unclear whether diet consistent with Harvard HEP plays similarly important role in curbing disease epidemic in Asian population.

Chinese diet consumption has been characterized by a rapid decline in intake of coarse grains and increases in intake of edible oils, and animal-source foods over the past two decades. It is unknown how Chinese diet quality changed as a whole over time. Although China issued Chinese dietary guidelines (CDG) in 2007, there is lack of an index based on its diet recommendation to assess overall diet quality. Moreover, it deserves concerns of potentially different health benefits due to many difference in the basis and recommendations between Harvard HEP and CGG. We proposed to evaluate average index-based diet quality transition, identify heterogeneous trajectories of diet quality, and related change patterns of diet quality to major CM risks in Chinese population.

We used longitudinal data from the China Health and Nutrition Survey (CHNS). This survey covers a wide range of high-quality longitudinal data including diet, sociodemographic factors, anthropometrics, blood pressure, physical activity and smoking status between 1991 and 2011, as well as biomarker data obtained from fasting blood samples collected in 2009. Thus, CHNS offers a unique opportunity to understand long-term diet quality transition and the association between overall diet quality and the risk of diabetes and CM risks among Chinese population.

Research Aims

Aim 1: Examine the association between diet quality in 2006 and prevalence of diabetes and major CM risks in 2009 in Chinese adults.

1a. Construct China dietary quality index (CDQI) based on diet-related recommendations of the 2007 Chinese dietary guidelines (CDG) and tailor the AHEI-2010 (named as tAHEI) to match Chinese diet.

1b. Evaluate the association between each score (CDQI and tAHEI score) in 2006 and prevalence of diabetes and major CM risks over 3 y of follow-up including hemoglobin A1c (HbA1c), blood pressure, and plasma lipids using mixed-effect random intercept linear and logistic regression analysis.

We hypothesized that China DQI and tAHEI scores would be negatively associated with

CM risks among Chinese adults. The tAHEI would be a better predictor of health outcomes, while CDG is Chinese-specific guidelines.

Aim 2: Investigate secular trends in diet quality and potential sociodemographic disparity from 1991 to 2011 in the Chinese adults using the tAHEI score to assess diet quality in Chinese adults.

We first used LMS method [the L curve (Yeo-Johnson to remove skewness), M curve (median) and S curve (coefficient of variation)] to present gender-specific distribution characteristics of overall diet quality assessed by the tAHEI score. Then we performed longitudinal quantile regression models to investigate shifts in tAHEI scores at different percentiles in comparison with average secular trend of diet quality. Finally, we used mixed-effect linear random intercept regression to evaluate sociodemographic disparity in average diet quality transition by considering potentially significant effect modification measure and predicted sociodemographic specific tAHEI scores.

We hypothesized that the tAHEI score of Chinese adults would show non-linear increasing trends with increased proportion of adults had higher scores and differential rate of increase across the percentiles over time. Moreover, we hypothesized diet quality transition would vary significantly across sociodemographic groups and the gaps in diet quality between northern and southern adults would become widened over 20-year period.

Aim 3: Examine the impact of fifteen-year trends in diet quality from 1991 to 2006 on Diabetes Prevalence in 2009 among adults.

3a. Examine the association between baseline diet quality and diabetes-related biomarkers including fasting glucose, HbA1c, insulin, homeostasis model of insulin resistance (HOMA-IR) and diabetes prevalence.

3b. Examine the association between changes in diet quality and diabetes-related biomarkers.

We hypothesized that high baseline diet quality and high improvement in diet quality were independently associated with lower diabetes-related biomarkers and lower prevalence of diabetes.

CHAPTER 2: LITERATURE REVIEW

The rising epidemics and burden of chronic disease in China

The rising epidemic of obesity, diabetes and associated cardiometabolic (CM) risks have been public health concern worldwide [1]. This is especially pertinent for Asian countries given that these settings have faced more drastic socioeconomic and nutrition transitions [2-4] and Asians tend to pose higher CM risks at lower BMI level [5] and at younger ages relative to western populations [6]. It was shown that approximately 42% of Chinese children, 85% of Chinese adults aged 40 years and older [7], 33.2% of non-overweight Chinese adults had high levels of at least one CM risk factor in 2009 [8]. The prevalence of diabetes in Chinese adults was 0.67% in 1984, 2.5% in 1994, and 9.7% in 2010 among adults in China. The diabetes mortality and disability adjusted life years between 1990 and 2000 increased by 45.0% and 10.3%, respectively. To curb the rising epidemic and expanding burden of obesity and related CM risks in China, effective actions call for evidence-informed, scientifically evaluated strategies and policies. [4, 9]

Rapid shifts in Chinese food consumption call for a way to capture multidimensional complexity of diet as a whole

Over the past two decades, China has experienced marked shifts in diet [10, 11] and PA [12, 13] along with its rapid economic growth and social changes and the concurrent shifts in disease patterns[11]. 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. [10, 11, 14] Pork, especially fatty fresh pork, is the most predominant animal-source food consumed in China. [10, 15] Considering the multiple dimensions of the changes in the Chinese diet, the key issue is how to capture the dynamic complexity as a whole.

Index-based dietary patterns approach: an alternative way to fully investigate the overall diet - disease relationship

Recently, dietary patterns approach have gained extensive attention give its advantage of capturing the overall complexity of the diet, interaction or highly correlated nature of dietary consituents as oppossed to single nutrients, foods or food groups analysis. [16-21] Two common approaches are used to describe dietary patterns: a posteriori using data-driven methods and a priori using theory-defined methods. [9, 17, 19, 22]Although data-driven dietary patterns have the strengths of being related to actual dietary practices, they may not necessarily represent 'healthy diet' and their sample-specificity and lack of stability make it difficult to compare results across the studies. [18, 20, 21] In contrast, diet index-based dietary patterns are developed from current healthy dietary recommendations that allow for standardization of the scores and comparability of results across studies from different populations.[20] From the perspective of public health, governments, many scholars and others prefer 'healthy' dietary guidelines to enhance the overall diet quality by promoting directly eating certain 'healthier' foods and reducing consumption of selected 'bad or unhealthful' foods [23].

Why use the Althernative Healthy Eating Index-2010 to access Chinese diet quality?

Healthy Eating Pyramid (HEP) that was developed by the Harvard School of Public Health in 2005. [24] This Harvard guidance recommends using refined grains and red meat sparingly, emphasizes type of fat, multivitamin use, healthy oils and healthy protein like fish, beans or nuts, separates potatoes and French fries from vegetables, avoids sugar drinks and limits milk and dairy[24, 25]. Harvard HEP was suggested as most popular healthy recommendations by some researchers represent given its best available basis of global science independent of political and commercial pressures.

The Alternative Healthy Eating Index (AHEI)[26] and the most recent version of the AHEI-2010 [27] were developed from the recommendations of the Harvard HEP. The AHEI-2010 incorporated current scientific evidence on diet and health[27]. Compared with the AHEI, the AHEI-2010 add the components of sugar sweetened beverages and fruit juice and sodium, use two single components red/processed meat and long-chain fats instead of the ratio of white to red meat, whole grain instead of cereal fiber, percent of energy intake from PUFA instead of the ratio of polyunsaturated to saturate fat and delete duration of multivitamin use [27].

Previous studies from the Nurses' Health Study (NHS) and Healthy Professional's Follow-up Study (HPFS) indicated that the original AHEI was nearly twice as predictive of overall chronic disease risks than was the original HEI in US adults [28-31] and was also associated with decreased risk of type 2 diabetes[32]. However, there may be a potential problem that some components of the original AHEI and the AHEI-2010, such as nuts, vegetable, fruit, cereal and alcohol consumption, were on the basis of diet-disease relationships in the same cohorts. With regard to this point, several studies have confirmed the health effect of the AHEI in other populations. The other two studies in the British population of the Whitehall II prospective cohort study suggested significant association of the AHEI score with higher odds of reversal of the Metabolic syndrome, [33] and reduced risk of mortality. [34] Also, the AHEI-2010 showed better prediction of chronic disease risk than several other indices assessing adherence to the 2005 Dietary Guidelines for American in US population, such as the HEI-2005. [27, 35] One recent Meta-analysis of cohort studies in US, England and Europe population indicated that diets that score highly on the HEI, AHEI, and DASH are associated with a significant reduction in the risk of all-cause mortality, cardiovascular disease, cancer, and type 2 diabetes mellitus by 22%, 22%, 15%, and 22%, respectively.[36] These findings suggested the key role of the Harvard HEP in combating major chronic disease in many Western populations. However, it remains unclear whether the Harvard HEP plays similarly health benefits in Asian population. One recent study showed negative association of the AHEI-2010 with hip fracture among Singapore Chinese. [37]

Concerns about the discrepancy between Chinese dietary guidelines and Harvard HEP

China has its own food-based Chinese dietary guidelines (CDG). The latest version was released in 2007 with emphasis on promoting balanced diet. [38] There are a couple of differences between CDG and Harvard HEP: the focus of chronic diseases prevention in Harvard HEP versus the fight for double burden of under- and over-nutrition in most Asian DGs; food-and nutrient-based Harvard HEP versus food-based Asian DGs; the basis of strong global evidence of diet-chronic disease association from large-scale prospective studies for Harvard HEP versus the basis of local dietary practices, nutritional status and general sense about healthy diet for Asian DGs. Given better predictive of disease risk for AHEI-2010 or AHEI than other indices due to inclusion of fat and carbohydrate subtypes[5,27], potentially diffential health effect of adherence to both guidance warrants further study.

Advanced statistical methods to evaluate longitudinal trends in overall diet quality in depth

Traditional linear regression requires independence with observations. However, longitudinal repeated data violate this assumption given the correlation and dependence across multiple measurement of diet for each subject. In contrast, mixed-effect linear or logistic regression had the advantages of handing repeated measure, relaxing the assumption of observation independence, dealing with unbalanced data, and controlling for the unobserved heterogeneity.[39]

Why use China Health and Nutrition Survey (CHNS)?

The CHNS is an over 20-year longitudinal study and designed to examine how the social and economic transformation in China is affecting the health and nutritional status of its population (Popkin et al. 2009). The CHNS, initiated in 1989, has been completed in nine rounds (1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009 and 2011).

The CHNS used a multistage, random cluster process to draw the sample from the nine provinces of Heilongjiang (enrolled in 1997), Liaoning (not surveyed in 1997), Shandong, Henan, Jiangsu, Hubei, Hunan, Guizhou, and Guangxi. The provinces vary substantially in geography and economic development. Counties and cities in each province were stratified by income and a weighted sampling scheme was used to randomly select four counties and two cities (provincial capital and a lower income city) in each province. Villages/townships within the counties and urban/suburban neighborhoods within the cities were selected randomly as the primary sampling units. In each type of community, 20 households were randomly selected and all individuals in each household were surveyed for all data in each wave[40].

China provides a valuable basis of evaluating health benefit of adherence to Asian FBDG. The CHNS can capture the rapid sociodemographic, environmental and nutritional transition that characterized Asian societies in the most recent decades[41]. It also offer a unique opportunity to examine the efficacy of adherence to Harvard HEP and CDG in predicting CM risks in depth.

The dietary intake information in the CHNS at each wave combined the individual dietary intake collected by interview-administrated consecutive three-day 24-hour dietary recalls, food frequency questionnaires on soft drink and alcohol consumption in the past year, and household dietary weighing on the same three days. The combined method could provide accurate foods consumption data and decrease intra-individual variation [42]and perform particularly well to evaluate usual diet intake based validation studies from the CHNS[43, 44]. Therefore, diet data of the CHNS are very powerful to study Chinese long-term diet quality transition and evaluate diet-disease relationship.

The CHNS has measured outcome data with good quality control. Repeatedly measured anthropometric data and blood pressure avoid reporting bias of self-reported data[45-47]. The lipid- and diabetes-biomarker data from the 2009 fasting blood sample allow us to evaluate the association between dietary quality, continuous lipid profiles and dyslipidemia, and continuous diabetes-markers and diabetes risk, which is of important implications given dyslipidemia and diabetes thought as independent risk factors of CVD. Moreover, rich time-varying covariates including sociodemographic factors, physical activity, smoking status, and community urbanization contribute to good control for potential confounding and allow us fully examine the independent association of diet quality with disease risks.

CHAPTER 3:DIET QUALITY AND THE PREVALENCE OF DIABETES AND MAJOR CARDIOMETABOLIC RISK FACTORS AMONG ADULTS IN CHINA

Overview

Adherence to the Harvard indexes**,** the Alternate Healthy Eating Index (AHEI) and the most recent version AHEI-2010 have been inversely associated with risk of diabetes, cardiovascular disease, cancer and related mortality in the US, England, and Europe population. It remains unclear whether these associations are generalized to Asian population. Besides, there is lack of the 2007 Chinese dietary guidelines (CDG)-based index to measure Chinese diet quality and related association with disease risk. We developed China dietary quality index (CDQI) from the diet recommendations of the 2007 CDG and tailored the AHEI-2010 to match Chinese diet (named as tAHEI). Then we examined the association between Chinese diet quality as assessed by the CDQI and tAHEI score with prevalence of diabetes and major CM risk over 3 y of follow-up (2006-2009) among adults in China. Participants aged 18 to 65 (n=4440) from the longitudinal China Health and Nutrition Survey (CHNS) with food consumption data from three consecutive 24-hour dietary recalls were used to calculate adherence to both the tAHEI and CDQI. Multivariable logistic regressions were performed to analyze the associations of each index score in 2006 with the prevalence of diabetes and major CM risk factors in 2009. The baseline median CDQI scores and tAHEI scores for both sexes were lower than 50.0 points, reflecting relatively poor dietary quality. After adjustment for potential confounders, participants in the top compared with the bottom quintile of the tAHEI scores showed 36% lower prevalence of high low-density lipoprotein cholesterol (LDL-C) [odds ratio (OR): 0.64; 95% CI: 0.46, 0.90] in men and 33% lower prevalence (OR: 0.67; 95% CI: 0.49, 0.91) in women, while the CDQI scores showed 35%

lower prevalence of high LDL-C in the top versus bottom quintile (OR: 0.65; 95% CI: 0.46, 0.92) in men only. Further, the CDQI scores indicated 55% lower prevalence of diabetes in the top versus bottom quintile (OR: 0.45; 95% CI: 0.23, 0.87) in men only, whereas a null association was observed for the tAHEI scores for both sexes. Higher CDQI score was associated with 51% higher prevalence of elevated triacylglycerol (TAG) in the top versus bottom quintile in women only. These suggest that diet quality that highly scored by the CDQI and tAHEI showed similarly negative association with high LDL-C prevalence, whereas only the CDQI score was negatively related to diabetes prevalence in men but positively associated with elevated TAG prevalence in women.

Introduction

The rising epidemic of obesity, diabetes and associated cardiometabolic (CM) risks have been public health concerns worldwide in the past decade [1]. This is especially pertinent for Asian countries given that these settings have faced very rapid socioeconomic and nutrition transitions [2, 3, 48, 49] and Asians tend to have higher CM risks at lower BMI level [5] and at younger ages relative to the Western populations [6]. It was shown that approximately 85% of Chinese adults aged 40 years and older [50], and 33.2% of non-overweight Chinese adults had high levels of at least one CM risk factor in 2009 [8].

Chinese diet consumption has been characterized by a rapid decline in intake of coarse grains and increases in intake of edible oils, and animal-source foods over the past two decades[10]**.** Many studies have suggested that dietary patterns approach is a good way to capture the overall complexity of the diet as well as to examine health effect of diet quality as oppossed to using single nutrients, foods or food groups [16-20]. Furthermore, diet index-based dietary patterns are developed from current healthy dietary recommendations that allow for standardization of the scores and comparability of results across studies from different populations (Hu 2002).

Harvard Healthy Eating Pyramid (HEP) is the most popular healthier diet guidance given its best available basis of globally scientific evidence on diet-disease relationship[24, 25, 51]. The Alternative Healthy Eating Index (AHEI) [26] and the most recent version of the AHEI-2010 [27] were developed from the recommendations of the Harvard HEP. Previous studies from the Nurses' Health Study (NHS) and Healthy Professional's Follow-up Study (HPFS) indicated that the original AHEI was nearly twice as predictive of overall chronic disease risks than was the original HEI in US adults [28-31] and was also associated with decreased risk of type 2 diabetes[32]. The other two studies in the British population of the Whitehall II prospective cohort study suggested significant association of the AHEI score with higher odds of reversal of the Metabolic syndrome [33], and reduced risk of mortality [34]. Also, the AHEI-2010 showed better prediction of chronic disease risk than several other indices like the HEI-2005 assessing adherence to the 2005 Dietary Guidelines for American in US population[27, 35]. One recent Meta-analysis of cohort studies in US, England and Europe population indicated that diets that score highly on the HEI, AHEI, and DASH are associated with a significant reduction in the risk of all-cause mortality, cardiovascular disease, cancer, and type 2 diabetes mellitus by 22%, 22%, 15%, and 22%, respectively[36]. These findings suggested the key role of the Harvard HEP in combating major chronic disease in many Western populations; however, it remains unclear whether the Harvard HEP plays similarly important role in Asian population.

China has its own food-based Chinese dietary guidelines (CDG). The latest version was released in 2007 with emphasis on promoting balanced diet [52]. Given its basis of Chinese diet practice, the diet recommendations from CDG may be Chinese-specific and adherence to CDG may have the potential health benefit in preventing chronic disease. However, the basis of general sense on healthy diet rather than Chinese-specific diet-disease relationship evidence needs further study. To date, no index is yet developed to assess adherence to the

2007 CDG and little is known about its association with CM risk in Chinese adults.

The present study was to construct China dietary quality index (CDQI) from the diet recommendations of the 2007 CDG and to tailor the AHEI-2010 to match Chinese diet (named as tAHEI). Then we examined the association between diet quality as assessed by the CDQI and tAHEI score in 2006 with prevalence of type 2 diabetes, prediabetes, elevated blood pressure (BP), and lipid-related CM risk in 2009 among Chinese adults aged 18 to 65 across 3 years of the China Health and Nutrition Survey (CHNS).

Methods

Study Population

All data used in this study were derived from the China Health and Nutrition Survey (CHNS), an ongoing longitudinal study. The CHNS was initiated in 1989, with a focus 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[49, 53]. The CHNS used a multistage, random cluster process to draw the sample from the original eight provinces, and communities were selected randomly as the primary sampling units. In each type of community, 20 households were randomly selected and all individuals in each household were surveyed for all data in each wave. The sampling procedure has been described in detail elsewhere[10, 53]. The CHNS have been completed in nine rounds (1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009 and 2011). Fasting blood samples were collected for the first time in 2009.

Our analysis linked the dietary intake and covariates measured in 2006 with CM risk measured in 2009. Of 5,089 eligible subjects aged 18 to 65 who had complete diet data in 2006 and CM risk factor data in 2009, we excluded those having implausible energy intakes (n=38; < 1,000 kilocalories [kcal] per day or > 6,000 kcal for men and < 800 kcal or > 5,000 kcal for women), pregnant or lactating women (n=70), and those having missing covariates (n=102), those previously diagnosed by a doctor with diabetes, stroke, and myocardial infarction (n=88), and those having missing BMI or waist circumference (WC; n=351). Our final sample consists of 4,440 participants (2,062 males; 2,378 females).

The protocol of the survey was 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 gave written informed consent for their participation in the protocols.

Dietary Measurement

Dietary intake was assessed in 2006 using three consecutive 24-hour recalls for each individual, combined with a household weighing inventory of all available foods over the same period. The detailed diet data collection has been described elsewhere[10, 49, 54]. We linked dietary intake data to the China Food Composition Table (FCT) [55]. We additionally linked all Chinese foods to the USDA Food and Nutrient Database for Dietary Studies (FNDDS) [56] and National Nutrient Database for Standard Reference [57] to estimate fatty acid composition which is unavailable from the China FCT. We used the 3-day average intake of total energy intake (TEI), nutrients, and food/food groups to calculate the CDQI and AHEI scores in the analyses.

Construction of the CDQI

The Chinese Dietary Guidelines (CDG), food-based national policy released in 2007, aim to prevent both under-nutrition and chronic diseases [38, 52]. This guidance provides ten items of qualitative recommendations covering diet, physical activity (PA), alcohol use, healthy weight, and food safety. Chinese Food Guide Pagoda (CFGP) represents six established energy requirement -specific quantitative recommendation of intakes of relevant foods [38]. We referred to Chinese Dietary Recommendation Intake (CDRI)[58] to determine age-sex-specific energy requirement and related food intake recommendations for adults (Supplement Table 3.1).

To investigate the independent association between diet composition and each CM risk factor, we developed the CDQI based on only diet-related recommendations. The components of the CDQI along with criteria for maximum and minimum scores and formula used to calculate intermediate scores are presented in Table 3.1. Briefly, the CDQI consists of six adequacy components [coarse grains, total vegetables (include proportion of dark-color vegetables), fruits, nuts/soybeans/products, milk and products, and seafood] and four moderate components (red meat and poultry, edible oil, salt and alcohol consumption). Each component is scored on a continuous scale from 0 to 10. Therefore, the total CDQI score has a possible range of 0-100, with higher score indicating better compliance with the dietary guidelines. We used the following equation to calculate the intermediate score of each component.

For adequacy components: component score = (Maximum score / (A_{max}-A_{min}))*(X-A_{min});

For moderate components: component score = Maximum score - maximum score / (A_{max}-A_{min}))*(X-A_{min});

A_{max} is maximum amount of the component corresponding to recommended intake.

A_{min} is minimum amount of the component corresponding to recommended intake;

X: amount of each food group consumed by the individual.

Tailoring of the Harvard AHEI-2010 to match Chinese diet data

We tailored the Harvard AHEI-2010, developed from best and latest global evidence on food- and nutrient-disease relationships[27], to match our diet data and we named it as tAHEI. The detailed methods were shown in Table 3.2. Major tailoring includes: (1) for several foods measured by servings-unit, such as vegetables, fruit, nuts and legumes, red/processed meat, and sugar-sweetened beverages (SSB) and fruit juice, we changed servings-unit into grams-unit to scale these components; (2) we estimated usual intakes of alcohol and sugar sweetened beverage (SSB) from a food frequency questionnaire over the past year to reduce the potential underestimation of 24 h recall due to episodically consumption; (3) Given that Chinese whole grain intakes, defined as carbohydrate to fiber ≤ 10:1 [59] in the Harvard AHEI-2010, were extremely low and lack of variation, we replaced it with cereal fiber component which was chosen to develop the Harvard AHEI in 2002 by McCullough et al.[30]; (4) we scaled 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 64g [60]; (5) we use the past year FFQ of alcohol consumption and change grams of each type of alcohol (beer, wine and liquor) into oz and then calculated total number of drinks accounting for different portion size of alcohol subtypes; (6) we omitted *trans* fat component in the tAHEI given a lack of information on *trans* fat composition of all eaten food in both China and USDA FCT. Due to the omission of *trans* fat component, the tAHEI score ranged from 0 to 100, with higher score indicating better compliance with the dietary guidelines.

Assessment of CM risk factors

In the 2009 CHNS, overnight fasting blood samples were collected with venipuncture by trained experienced physicians, phlebotomist or nurses. Plasma and serum samples were then frozen, and stored at -86 ℃ for later laboratory analysis. All samples were analyzed in a national central lab in Beijing with strict quality control. Laboratory analysis methods for the CM biomarkers are described in detail elsewhere[48].

Three BP measurements were taken in a seated position after at least 5 min of rest in a quiet room and on the right arm by trained and certified health workers or nurses who followed a standardized procedure using regularly calibrated mercury sphygmomanometers. Participants were advised to avoid cigarette smoking, alcohol, caffeinated beverages and exercise for at least 30 min before the measurement. Systolic blood pressure (SBP) was measured at the first appearance of a pulse sound (Korotkoff phase 1) and diastolic blood pressure (DBP) at the disappearance of the pulse sound (Korotkoff phase 5)[61].

We focused on elevated BP, impaired Hemoglobin A1c (HbA1c) and lipids-related risk factors. We used International Diabetes Federation definitions [62] for elevated BP in adults (the mean of SBP ≥130 or the mean of DBP ≥85 or taking anti-hypertension medication) , for combined prediabetes and diabetes (HbA1c ≥5.6%,), diabetes (HbA1c ≥6.5%), lipid-related risk factors including elevated triacylglycerol (TAG >150 mg/dl), high low-density lipoprotein cholesterol (LDL-C > 130 mg/dl), low high-density lipoprotein cholesterol (HDL-C<40 mg/dl for men, < 50mg/dl for women). We choose HbA1c as indicator of glucose control to capture long-term glycemic exposure in Chinese population[63, 64].

Assessment of Covariates

Trained interviewers used standard questionnaires to collect information on annual family income, individual education level, physical activity, smoking status and community information. We categorized baseline age to 18- <35 years, 35- <50 years, 50-<65 years. We calculated per capita annual family income by dividing annual family income by household size, categorized by tertiles. We divided individual education level as less than primary school, complete 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[65]. We categorized continuous urbanicity index by tertiles. Further, we also considered geographical factor as northern, central and southern provinces, due to different dietary intake shown in previous studies[66, 67] .

Physical activity (PA) includes four domains: occupational, household chore, leisure time, and transportation activities. All activities were reported in average hours per week during the past year.[13] We converted time spent in each activity into metabolic equivalent of task (MET) hours per week based on the Compendium of Physical Activities[68]. The MET hours per week measurement accounts for both the average intensity of each activity and the time spent in each activity. We categorized total MET hours per week into tertiles (light, moderate, and heavy).

We also considered smoking status (dichotomized as 1 = current smoker and 0 = former or never smoker), baseline BMI, baseline waist circumference, and TEI as potential confounders.

Statistical Analysis

All analyses were performed separately for men and women. We categorized all participants into quintiles of baseline CDQI and tAHEI scores by gender, respectively, to examine the association of different levels of adherence to each score with each CM risk. We presented the median value and its range of each quintile of each score and used Wilcoxon rank sum for significance test of gender difference. For baseline characteristics of the participants, we used chi-square tests for categorical variables and general linear regression for continuous variables to test differences and trends across quintiles of the CDQI and tAHEI scores, respectively. We also calculated gender-specific Pearson's correlation coefficient between the two scores and did contingence table of quintiles of the CDQI score by quintiles of the tAHEI score to see how differently the participants were classified by them.

We constructed a series of multivariable logistic regression models to assess the association of adherence to the CDQI and the tAHEI with each CM risk factor, adjusting for all potential confounders and accounting for the clustering at the community level in the estimation of variation using the cluster option in regression analyses. We also tested linear trends by assigning median values to quintiles of the CDQI or tAHEI score and modeled this variable as a continuous term.

We conducted all statistical analyses using SAS version 9.2 (SAS Institute Inc., NC) and Stata version 12.0 (StataCorp., TX). All statistical tests were two-tailed and considered significant at $P < 0.05$.

Results

Baseline Characteristics

The baseline characteristics of participants across the quintiles of the CDQI and tAHEI score by gender are summarized in Table 3.3 and 3.4. The baseline median CDQI scores of men (38.5; range: 5.7, 82.1) was significantly lower than that of women (42.8; range: 8.1, 84.9) ($p<0.0001$), whereas the baseline median tAHEI scores of men (49.4; range: 13.0, 78.5) was higher than that of women (45.2; range: 12.1, 74.2) ($p<0.0001$). Both median scores are lower than 50 points, reflecting worse adherence in general.

The Pearson correlation between the CDQI and tAHEI scores was 0.48 ($P<0.0001$) in men and 0.56 ($P<0.0001$) in women. As categorized into quintiles of the CDQI and the tAHEI scores, about 31.1% of men and 35.2% of women were classified in the same quintiles (data not shown here).

Men and women in higher quintiles of the CDQI scores tended to live in Northern provinces and have lower daily TEI. Besides, there was higher proportion of women in the top compared with bottom quintile of the CDQI score who had high income (40.0% vs.

30.7%), had light physical activity (41.5% vs. 30.7%) and lived in highly urbanized community (38.3% vs. 31.4%)(Table 3.3).

In contrast, men and women in higher quintiles of the tAHEI scores tended to live in Northern provinces but have higher daily TEI. Besides, in the top compared with bottom quintile of the tAHEI scores, there was higher proportion of men who had high income (42.0% vs. 29.1%) and had higher BMI and waist circumference and higher proportion of women who had high income (41.7% vs. 28.0), lived in highly urbanized community (41.3% vs. 29.3%), had light physical activity (35.4% vs. 30.1%) and had higher BMI and waist circumference (Table 3.4).

Comparison of nutrient composition across the quintiles of the CDQI and tAHEI scores

As shown in supplement Table 3.2, most nutrients are significantly associated with both scores, except the intakes of cholesterol and vitamin A in men for the CDQI score and the intakes of vitamin A, vitamin C, vitamin E (women only) and selenium with the tAHEI score.

In men, higher CDQI score was associated with lower intakes of TEI, fat and sodium but with higher intakes of carotene and calcium, whereas higher tAHEI score was associated with higher intakes of TEI, fat, fiber, protein, vitamin E, potassium, calcium, iron, zinc and phosphorus.

In women, higher CDQI score was associated with lower intakes of TEI, fat and sodium but with higher intakes of fiber, vitamin C, potassium , calcium, iron, and phosphorus, whereas higher tAHEI score was associated with higher intakes of TEI, fiber, cholesterol, protein, potassium, calcium, iron, zinc and phosphorus.

In addition, the gap in sodium intake in the top compared the bottom quintile was much wider for the CDQI scores than for the tAHEI scores (3000mg vs. 500mg) as opposed to much wider gaps for the tAHEI scores than for the CDQI scores in the intakes of vitamin E (25.8mg vs. -0.2mg) , calcium (249.1mg vs. 129.5mg), iron (7.0mg vs. 2.2mg), zinc (1.9mg vs. 0.4mg) and selenium (17.7mg vs. 5.4mg)) in adult men. Similar results were also found in adult women.

Associations of the CDQI and tAHEI scores with selected CM risk factors

Table 3.5 shows the ORs of diabetes and major CM risk factors according to quintiles of the CDQI and tAHEI scores in Chinese men. After adjustment for all potential confounders, adult men in the top compared with the bottom quintile of the CDQI score showed 55% lower prevalence of diabetes [odds ratio (OR): 0.45, 95% CI: 0.23–0.87], whereas the tAHEI score was not associated with diabetes prevalence significantly. The two indices were negatively associated with prevalence of high LDL-C to a similar extent (OR for CDQI: 0.65, 95% CI: 0.46–0.92; p-trend <0.01; OR for the tAHEI: 0.64; 95% CI: 0.46–0.90; p-trend <0.01).

After adjustment for all potential confounders, women in the top compared with the bottom quintile of the tAHEI score showed 33% lower prevalence of high LDL-C (OR: 0.67; 95% CI: 0.49–0.91), while women comparing extreme quintile of the CDQI score showed 51% higher prevalence of elevated TAG (OR: 1.51, 95% CI: 1.08–2.11), although none of linear trend tests were statistically significant. Null associations of both scores were observed with the prevalence of diabetes, prediabetes and diabetes, low HDL-C, and elevated BP in women (Table 3.6).

All regression models for both CDQI and tAHEI scores were also performed adjusting additionally for baseline BMI and waist circumference, respectively, and conclusion from the results were not changed (data not shown).

Discussion

In this study we developed an *a priori*-defined diet index based on the diet-related recommendations of the 2007 Chinese dietary guidelines and simultaneously investigated Chinese diet quality as assessed by the CDQI and the tAHEI with the prevalence of type 2 diabetes as well as major CM risk factors. We found that only one third of the participants were classified into the same quintiles of both index. The 2 indices reflected different nutrient profiles to some extent, especially in terms of TEI, fat, percentage of energy from fat, and some vitamins and minerals. Moreover, our study indicated that better adherence to the CDQI scores was associated with a 55% lower prevalence of diabetes in Chinese men only, whereas the tAHEI scores were not associated with diabetes prevalence in either gender. As for lipids-related CM risks, higher CDQI score was related to about one third lower prevalence of high LDL-C risk in men but higher prevalence of elevated TAG in women, whereas the tAHEI score shows negative association with high LDL-C prevalence in men and women. Besides, null associations were observed for the two indices and the prevalence of elevated BP, prediabetes and diabetes together, and high HDL-C.

A previous study indicated a 31% and 33% lower risk of CHD and diabetes related to higher AHEI-2010 scores in the Nurses' Health and Health Professionals Follow-up cohorts[27, 32]. One recent Meta-analysis of cohort studies in US, England and Europe population indicated that diets that score highly on the HEI, AHEI, and DASH are associated with a significant reduction in the risk of type 2 diabetes mellitus by 22%[36]. However, our results do not indicate consistent findings related to tAHEI in China population. There are several possible reasons to explain our null findings for the tAHEI with diabetes prevalence. First, adult men and women had lower median tAHEI score and narrow gaps across the quintiles, which may fail to detect significant associations due to lack of enough variation. Second, the AHEI-2010 was not based on Asian population-scientific evidence of diet-disease relationship and the evidence-based threshold effect of each component of the AHEI-2010 may be population disparity. Jacobs' study in the Hawaiian component of the multiethnic cohort suggested that higher AHEI-2010 score 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 years[69]. Third, our study assessed daily food and nutrient intake using interviewer-administered 3 consecutive 24 hour recall, which may be subject to under-estimate episodically consumed foods in comparison of usual intake estimates from food frequency questionnaires. In addition, we assessed the effect of 3 y follow-up, but those studies investigated predictive of diabetes risk over 10 years follow-up. Finally, the tAHEI in our study was not identical to the original Harvard AHEI-2010 [27] due to several tailoring ways, including the use of US nutrient database to estimate fatty acid intakes, the omission of *trans* fat component and the use of dietary fiber component instead of whole grain. In addition, we calculated the intake of insoluble fiber rather than total fiber from cereal given lack of soluble fiber data in the China FCT. This may underestimate cereal fiber intake and consequently lower its score. The aforementioned tailoring key components of the Harvard AHEI-2010 may have contributed to more strong prediction of disease risk[27, 51]. Studies have indicated a positive association of trans fat with risk of diabetes [70, 71] and with increased LDL-C[72], and a negative association with risk of decreased HDL-C[72]. Mozaffarian suggested the definition of whole grains with less than 10:1 ratio of total carbohydrate to fiber as the most healthful, which was used in the Harvard AHEI-2010. Several comparative studies indicated that better predictive capacity of the Harvard AHEI-2010 or the AHEI on disease risk may be due to its additional dietary information including emphasis on increasing intake of whole grains, reducing intake of sugar-sweetened beverages, and refining dietary fat quality [27, 28, 30, 32].

Our study is the first to create CDQI based on recommendations of the 2007 CDG [38, 52]. The 2007 CDG emphasizes promoting balanced diet on the basis of general sense on healthy diet but lack of sufficient evidence on diet-disease relationship among the Chinese population. Several relevant issues on the CDG need to be considered. First, the CDG should not provide a single recommended intake of combined red meat and poultry given red meat and poultry had differential impact on health outcomes; Second, coarse grains, defined as tuber, beans and other cereals excluding rice and wheat in the China food grouping system, was quite different from the whole grains in terms of health benefits. With regard to the development of CDQI, refining the quality of total vegetables (light- or dark-color) and considering age-sex-energy requirement-specific recommendation of relevant food intakes may be advantageous to assess the overall dietary quality and improve the prediction of CM risk. However, gender disparity of CDQI score related to prevalence of diabetes and elevated TAG are not understood well and warrant further study.

Strengths of this study include the use of earlier dietary intake from the 2006 wave of survey to estimate prevalence of multiple health outcomes in 2009, rigorous measurement of diabetes ascertainment and lipid-related biomarkers, relative precise assessment of diet quality using 24 hour recall methodology and the collection of three days of intake as was shown in earlier research using the CHNS [42, 43, 46], and adjustment for a comprehensive range of potential confounders. The prospective nature of ascertainment for diabetes has advantage of clear temporality over cross-sectional design and reduces the possibility of reverse causality. Type 2 diabetes and prediabetes were diagnosed using HbA1c, which has advantage of assessing long-term glycemic exposure over a single measure of glucose and is reliable for diabetes diagnosis in Chinese population[63, 64] . Further, interviewer-administered 24-hour dietary recalls are a good way to assess adherence to healthy dietary recommendations on a daily basis given its ability to capture extensive and complete information on all foods and beverages consumed.

Our study also has limitations. First, only one time point of biomarker data in the 2009 CHNS makes it impossible to examine prospective associations between diet indexes and incident CM risk factors except elevated BP. However, our analysis excluded those with known diabetes, stroke and MI in 2006, which may reduce the possibility of changes in dietary intake resulting from existing disease. Second, three consecutive 24-hour dietary recalls may have relatively limited correction for within-subject variation, especially for episodically consumed foods. Third, our analysis had a small number of incident cases of type 2 diabetes in 3-year period and consequently limited our power to detect associations. Further, the same total score may result from the sum of quite different component scores; however, the nature of the predefined indexes is to assess overall diet quality. Further study to identify the relevant individual components contributing to reduced risk may help understanding diet-specific pathways for each CM risk.

In summary, this study had shown that the CDQI, which assesses adherence to CDG, was inversely associated with the prevalence of diabetes and high LDL-C in men only and the tAHEI was beneficially associated with the prevalence of high LDL-C in both men and women. To the best of our knowledge, this is the first study to investigate simultaneously the associations between adherence to CDQI and the tAHEI with diabetes and lipid-related CM risk factors in the Chinese population. The association of adherence to tAHEI score with decreased prevalence of high LDL has important health implications given its important role on the context of rapidly increasing cardiovascular disease in the Chinese population. In the future, longitudinal association between long-term follow-up diet quality and incident CM risk incident CM risk warrants further investigation.

Tables and Figures

Table 3.1. Components of the CDQI and scoring methods according to the CDG and CFGP

Qualitative recommendations of CDG	Quantitative recommendations of CFGP	Components of CDQI	Criteria for minimum score (0) [1]	Criteria for maximum score [1]	Maximum score value
1. Eat a variety of foods, mainly cereals including a certain amount of coarse grains;	Grains/tubers/beans: 250 - 400 g/d; Coarse grains: 50-100 g/d	Coarse grains (other cereals excluding rice and wheat, tuber and beans)	0	≥ 75	10
2. Consume plenty of vegetables, fruits and tubers; (at least half of total vegetables are dark-colored)	Vegetables: 300 – 500 g/d	Total vegetables	0	≥ 300-500 [c]	5
		Dark-colored, ratio of dark-colored to total vegetables [2]	0	≥ 1/2	5
	Fruits: 200 - 400 g/d	Total fruits	0	≥ 200 – 400 [c]	10
3. Consume milk, soybean, or dairy- or soybean-products every day;	Nuts/soybean and soybean products: 30 - 50 g/d	Nuts/soybean/products	0	≥ 30-50 [c]	10
	Milk/products: 300 g/d	Milk/products	0	≥ 300	10
4. Consume appropriate amounts of fish, poultry, eggs and lean meat;	Fish and other seafood 50-100 g/d	Seafood	0	≥ 50-100 [c]	10
	Red meat and poultry: 50-75 g/d	Red meat and poultry [3]	≥ 50-75 [4]	0	10
5. Reduce cooking oil intake; Choose a light diet low in salt;	Edible oil: 25-30 g/d	Edible oil (g/d) [3]	≥ 2(25-30) [4]	<25-30 [c]	10
	Salt: 6 g/d	Salt (g/d) [3]	≥12	<6	10
6. If you drink alcoholic beverages, do so in limited amounts;		Alcohol drinking (g/d) [3]	Male: ≥ 50 Female: ≥30	Male: <25 Female: <15	10
		Total Score			100

Abbreviations: CDQI=China Dietary Quality Index; CDG=Chinese Dietary Guidelines; CFGP=Chinese Food Guide Pagoda.

[1] Participants with intakes between the maximum and minimum amount were assigned scores based on the formula: component score= (Maximum score / $(A_{max}-A_{min})$)*$(X-A_{min})$ for adequacy components; component score = Maximum score - maximum score / $(A_{max}-A_{min})$)*$(X-A_{min})$ for moderate components; A_{max} is maximum amount of the component corresponding to recommended intake. A_{min} is minimum amount of the component corresponding to recommended intake. X: amount consumed by the individual.

[2] Dark-colored vegetables are defined as ≥ 500 mcg carotene /100 g of vegetables.

[3] Moderate components in CDQI. For the components edible oil, salt, and alcohol drinking, we chose twice of the recommended maximum intake as the criteria for 0 point to increase the scoring variation.

[4] Age-sex-energy intake-specific recommended intakes of food groups (see Supplement Table 3.1).

Table 3.2. Tailoring method of the Harvard AHEI-2010

Components	Criteria for minimum score(0) [1]	Criteria for maximum score(10) [1]	Comments on tailoring
Vegetables, g/d [2]	0	≥591	5 servings/d (1 serving is 0.5 cup of vegetables)
Whole fruit, g/d [2]	0	≥473	4 servings/d (1 serving is 0.5 cup of berries)
Cereal fiber, g/d [2]	0	15	15 g cereal fiber as ideal on the basis of epidemiologic studies and the distribution in our cohorts.
Nuts and legumes, g/d [2]	0	28	1 serving/d was considered to be ideal on the basis of the AHEI recommendations and the current literature. One serving is 1 oz of nuts or 1 tablespoon (15 ml) of peanut butter. *
Long-chain (n-3) fats (EPA+DHA), mg/d [3]	0	250	The cutoff for optimal intake (250 mg/d) is about 100g/d of fish
PUFA, % of energy [3]	≤2	≥10	The highest score was given to individuals with 10% of total energy intake from PUFA. PUFA does not include EPA or DHA intake *
Red/processed meat, g/d [2]	≥170 (red meat)	0	An upper limit of 1.5 servings/d (1 serving is 4 oz of unprocessed meat or 1.5 oz of processed meat) *
Sodium, mg/d	Highest decile	Lowest decile	The cutoffs for sodium were based on deciles of distribution in the study population. This method is used by the AHEI-2010 due to lack of brand specificity in the FFQ to accurately estimate absolute intake.
SSB and fruit juice, g/d [2]	≥227	0	≥1 serving/d was considered to be the least optimal. 1 serving is 8 oz. We use the past year FFQ of SSB and fruit juice, instead of 3 consecutive 24 hour recall, to get more precise estimate of daily intake for episodically consumed SSB and fruit juice.
Alcohol, drinks/d [4]			
Women	≥2.5	0.5-1.5 (0-<0.5, score = 2.5)	One drink is 4 oz of wine, 12 oz of beer, or 1.5 oz of liquor. For both men and women with alcohol intake less than 0.5 including zero, we score this component 2.5 points.
Men	≥3.5	0.5-2.0 (0-<0.5, score = 2.5)	
Trans fat, % of energy	---	---	We omitted trans fat component in the tailored AHEI-2010 given a lack of information on trans fat composition of all eaten food in both China and USDA FCT.
Total score	0	100	

Abbreviations: AHEI=Alternative Healthy Eating Index; CHNS= China Health and Nutrition Survey; DHA= Docosahexenoic acid; EPA= Eicosapntemacnioc Acid; FNDDS=Food and Nutrient Database for Dietary Studies; HEP=Healthy Eating Pyramid; PUFA=polyunsaturated fatty acid; SR=standard references; SSB=sugar-sweetened beverages. [1] Intermediate intakes were scored between the minimum and the maximum according to the formula: component score= (Maximum score / (A_{max}-A_{min}))*(X-A_{min}) for adequacy components; component score = Maximum score - maximum score / (A_{max}-A_{min}))*(X-A_{min}) for moderate components (red/processed meat, sodium, SSB and fruit juice, and alcohol); A_{max} is maximum amount of the component corresponding to the recommended intake, while A_{min} is minimum amount of the component corresponding to the recommended intake. X: amount consumed by the individual. [2] Serving units were transferred to grams to match the CHNS diet data. (1 cup = 236.59 g; 1 oz = 28.35 g); [3] We additionally linked all Chinese FCT foods to the USDA FNDDS and SR nutrient databases to estimate fatty acid composition which is unavailable from the China FCT. [4] Grams units were transferred to drinks for alcohol component.

Table 3.3. Baseline Characteristics of participants according to sex-specific quintiles of the CDQI scores, CHNS

Characteristics	Men						*P*-trend[1]	Women						*P*-trend[1]
	Q1	Q2	Q3	Q4	Q5	Total		Q1	Q2	Q3	Q4	Q5	Total	
N	412	413	412	413	412	2062		475	476	476	476	475	2378	
Median[2]	24.2 (5.7, 29.4)	33.2 (29.5, 35.7)	38.5 (35.7, 42.0)	45.2 (42.0, 48.5)	53.9 (48.5, 82.1)	38.5 (5.7, 82.1)		28.8 (8.1, 33.3)	36.8 (33.4, 39.8)	42.8 (39.9, 45.7)	48.8 (45.7, 52.5)	57.4 (52.5, 84.9)	42.8 (8.1, 84.9)	
Age, %														
18-<35y	15.0	17.7	14.3	17.4	14.8	15.9		11.2	12.8	11.1	15.1	11.6	12.4	
35-<50y	39.6	41.6	39.3	38.5	39.1	39.6	0.49	43.6	43.5	44.7	45.8	43.8	44.3	0.56
50-<65y	45.4	40.7	46.4	44.1	46.1	44.5		45.3	43.7	44.1	39.1	44.6	43.4	
Income, %														
Low	32.8	33.2	33.7	37.5	29.4	33.3		**33.3**	**37.4**	**31.9**	**36.3**	**27.6**	**33.3**	
Median	36.2	32.9	32.0	33.2	32.5	33.4	0.20	**36.0**	**30.5**	**34.7**	**33.2**	**32.4**	**33.3**	**0.01**
High	31.1	33.9	34.2	29.3	38.1	33.3		**30.7**	**32.1**	**33.4**	**30.5**	**40.0**	**33.3**	
Education, %														
< primary	11.9	10.7	10.7	9.0	10.2	10.5		29.7	30.5	30.7	30.0	25.1	29.2	
Primary	19.4	18.2	18.4	18.9	25.2	20.0	0.20	23.6	21.4	18.9	20.2	21.3	21.1	0.35
> primary	68.7	71.2	70.9	72.2	64.6	69.5		46.7	48.1	50.4	49.8	53.7	49.7	
Urbanicity index ,%														
Low	**28.2**	**27.4**	**28.9**	**41.9**	**40.8**	**33.4**		**28.8**	**34.0**	**29.6**	**38.9**	**34.5**	**33.2**	
Middle	**43.7**	**37.0**	**36.2**	**27.1**	**22.8**	**33.4**	**<0.001**	**40.4**	**35.9**	**33.8**	**34.0**	**24.0**	**33.6**	**<0.001**
High	**28.2**	**35.6**	**35.0**	**31.0**	**36.4**	**33.2**		**30.7**	**30.0**	**36.6**	**27.1**	**41.5**	**33.2**	
Geographical region, %														
North	**10.0**	**11.9**	**17.5**	**28.8**	**41.3**	21.9		**9.5**	**11.1**	**19.7**	**27.3**	**47.2**	**23.0**	
Central	**31.6**	**36.6**	**32.3**	**33.2**	**31.6**	33.0	**<0.001**	**29.9**	**35.9**	**36.3**	**35.9**	**30.1**	**33.6**	**<0.001**
South	**58.5**	**51.6**	**50.2**	**38.0**	**27.2**	45.1		**60.6**	**52.9**	**43.9**	**36.8**	**22.7**	**43.4**	

Table 3.3. Baseline Characteristics of participants according to sex-specific quintiles of the CDQI scores, CHNS (continued)

Characteristics	Men						*P*-trend[1]	Women						*P*-trend[1]
	Q1	Q2	Q3	Q4	Q5	Total		Q1	Q2	Q3	Q4	Q5	Total	
Physical activity, %														
Light	31.1	36.6	34.0	29.8	35.2	33.3	0.06	**31.4**	**31.3**	**35.7**	**29.8**	**38.3**	**33.3**	**<0.001**
Moderate	34.5	32.0	33.0	36.3	31.1	33.4		**32.0**	**34.7**	**30.7**	**37.4**	**32.0**	**33.3**	
Heavy	34.5	31.5	33.0	33.9	33.7	33.3		**36.6**	**34.0**	**33.6**	**32.8**	**29.7**	**33.3**	
Currently smoking, %	60.7	60.3	58.3	56.7	54.1	58.1	0.29	2.3	2.1	2.9	3.6	4.6	3.1	0.16
BMI(kg/m^2)[3]	23.1±0.2	23.4±0.2	23.2±0.2	23.2±0.2	23.4±0.1	23.3±0.1	0.40	23.3±0.2	23.5±0.3	23.6±0.2	23.6±0.1	23.6±0.1	23.5±0.1	0.15
WC (cm)[3]	82.9±0.5	83.3±0.5	82.9±0.5	82.6±0.5	83.2±0.4	83.0±0.2	0.92	79.2±0.4	80±0.4	80.3±0.5	79.8±0.4	80.3±0.4	79.9±0.2	0.10
TEI(kcal/d)[3]	**2807.0±37.4**	**2733.9±40.2**	**2576.4±36.3**	**2539.5±36.6**	**2499.1±37.2**	2631.2±17	**<0.01**	**2391.8±30.8**	**2264.9±31.3**	**2207±29.6**	**2122.9±29**	**2084.6±29.7**	2214.2±13.6	**<0.01**

Abbreviations: CDQI=China dietary quality index; CHNS= China Health and Nutrition Survey. Q=quintile. WC=waist circumference. TEI=total energy intake. [1] Chi-square tests were used for categorical variables and general linear models were used for continuous variables to test differences between groups and trends. [2] Median; range in parentheses; [3] Mean ± SE (all such values).

Table 3.4. Baseline Characteristics of participants according to sex-specific quintiles of the tAHEI scores, CHNS

Characteristics	Men						*P*-trend[1]	Women						*P*-trend[1]
	Q1	Q2	Q3	Q4	Q5	Total		Q1	Q2	Q3	Q4	Q5	Total	
N	412	413	412	413	412	2062		475	476	476	476	475	2378	
Median[2]	36.7 (13.0, 41.0)	44.2 (41.1, 46.8)	49.4 (46.8, 51.7)	54.5 (51.7, 57.7)	62.5 (57.7, 78.5)	49.4 (13.0, 78.5)		34.6 (12.1, 38.0)	40.6 (38.0, 43.1)	45.2 (43.1, 47.6)	50.2 (47.6, 52.8)	57.4 (52.8, 74.2)	45.2 (12.1, 74.2)	
Age, %														
18-<35y	21.8	17.7	14.1	15.0	10.7	15.9		13.7	12.4	12.4	12.6	10.7	12.4	
35-<50y	36.2	37.8	39.6	37.0	47.6	39.6	<0.001	42.5	43.3	46.2	41.8	47.6	44.3	0.67
50-<65y	42.0	44.6	46.4	47.9	41.7	44.5		43.8	44.3	41.4	45.6	41.7	43.4	
Income, %														
Low	**35.7**	**37.0**	**32.8**	**33.9**	**27.2**	33.3		**37.3**	**32.6**	**37.2**	**34.0**	**25.5**	33.3	
Median	**35.2**	**30.8**	**36.7**	**33.4**	**30.8**	33.4	**<0.01**	**34.7**	**35.1**	**34.0**	**30.0**	**32.8**	33.3	**<0.001**
High	**29.1**	**32.2**	**30.6**	**32.7**	**42.0**	33.3		**28.0**	**32.4**	**28.8**	**35.9**	**41.7**	33.3	
Education, %														
< primary	10.2	12.8	12.6	8.7	8.0	10.5		**32.2**	**29.2**	**29.8**	**31.9**	**22.7**	29.2	
Primary	19.9	22.3	17.0	21.5	19.4	20.0	0.11	**21.9**	**22.1**	**20.6**	**19.5**	**21.3**	21.1	**0.04**
> primary	69.9	64.9	70.4	69.7	72.6	69.5		**45.9**	**48.7**	**49.6**	**48.5**	**56.0**	49.7	
Urbanicity index, %														
Low	31.6	36.1	37.6	32.0	29.9	33.4		33.3	38.2	37.0	31.1	26.3	33.2	
Median	34.5	33.9	34.5	32.7	31.3	33.4	**0.05**	37.5	30.0	33.8	34.5	32.4	33.6	**<0.001**
High	34.0	30.0	27.9	35.4	38.8	33.2		29.3	31.7	29.2	34.5	41.3	33.2	
Geographical region, %														
North	**10.7**	**16.5**	**20.9**	**23.2**	**38.1**	21.9		**12.6**	**20.6**	**21.0**	**25.2**	**35.4**	23.0	
Central	**15.0**	**32.7**	**42.0**	**40.9**	**34.5**	33.0	**<0.001**	**20.4**	**29.0**	**40.8**	**43.7**	**34.3**	33.6	**<0.001**
South	**74.3**	**50.8**	**37.1**	**35.8**	**27.4**	45.1		**66.9**	**50.4**	**38.2**	**31.1**	**30.3**	43.4	

Table 3.4. Baseline Characteristics of participants according to sex-specific quintiles of the tAHEI scores, CHNS (continued)

Characteristics	Men						*P*-trend[1]	Women						*P*-trend[1]
	Q1	Q2	Q3	Q4	Q5	Total		Q1	Q2	Q3	Q4	Q5	Total	
Physical activity, %														
Light	37.4	32.7	31.3	32.0	33.3	33.3		30.1	31.9	32.1	37.0	35.4	33.3	
Moderate	32.8	32.2	29.6	36.3	35.9	33.4	0.09	30.3	34.7	32.8	33.8	35.2	33.3	**0.02**
Heavy	29.9	35.1	39.1	31.7	30.8	33.3		39.6	33.4	35.1	29.2	29.5	33.3	
Currently smoking, %	56.3	56.4	60.2	56.4	60.7	58.1	0.50	**1.3**	**4.2**	**2.9**	**4.4**	**2.7**	3.1	**0.04**
BMI(kg/m^2)	**22.6±0.2**	**23.3±0.2**	**23.4±0.2**	**23.3±0.2**	**23.6±0.1**	23.3±0.1	**<0.001**	**22.9±0.1**	**23.4±0.1**	**23.8±0.2**	**24.0±0.3**	**23.6±0.1**	23.5±0.1	**<0.001**
WC (cm) [3]	**80.5±0.5**	**83.1±0.5**	**83.1±0.5**	**83.8±0.5**	**84.4±0.4**	83.0±0.2	**<0.001**	**78.3±0.4**	**79.7±0.4**	**80.9±0.5**	**80.5±0.5**	**80.1±0.4**	79.9±0.2	**<0.01**
TEI(kcal/d)	**2426.8±35.6**	**2557.0±35.7**	**2624.1±38.4**	**2741.3±38.1**	**2806.8±39.3**	2631.2±17	**<0.001**	**2069.2±27.5**	**2159.6±28.4**	**2180.2±28.3**	**2293.0±32.6**	**2369.1±33.3**	2214.2±13.6	**<0.001**

Abbreviations: tAHEI=tailored Alternative Healthy Eating Index; CHNS= China Health and Nutrition Survey. Q=quintile. WC=waist circumference. TEI=total energy intake.[1] Chi-square tests were used for categorical variables and general linear models were used for continuous variables to test differences between groups and trends. [2] Median; range in parentheses; [3] Mean ± SE (all such values).

Table 3.5. OR (95% CI) of the prevalence of CM risk across the quintiles of the CDQI and tAHEI scores in Chinese men, respectively, CHNS

	CDQI scores					*P*-trend[1]	tAHEI scores					*P*-trend[1]
	Q1	Q2	Q3	Q4	Q5		Q1	Q2	Q3	Q4	Q5	
Diabetes												
Cases (%)	33(8.0)	37(9.0)	29(7.0)	27(6.5)	21(5.1)		26(6.3)	24(5.8)	31(7.5)	37(9.0)	29(7.0)	
Model 1[2]	**1.00**	**1.04(0.63,1.72)**	**0.75(0.42,1.33)**	**0.65(0.36,1.17)**	**0.43(0.22,0.81)**[**]	**<0.01**	1.00	0.73(0.42,1.25)	0.89(0.53,1.48)	1.07(0.59,1.93)	0.76(0.41,1.40)	0.75
Model 2	**1.00**	**1.11(0.67,1.86)**	**0.77(0.44,1.38)**	**0.69(0.39,1.24)**	**0.45(0.23,0.86)**[*]	**<0.01**	1.00	0.71(0.41,1.21)	0.85(0.51,1.43)	1.06(0.59,1.89)	0.73(0.39,1.34)	0.69
Model 3	**1.00**	**1.11(0.67,1.87)**	**0.78(0.43,1.41)**	**0.70(0.38,1.27)**	**0.45(0.23,0.87)**[*]	**<0.01**	1.00	0.70(0.41,1.20)	0.83(0.49,1.40)	1.02(0.57,1.83)	0.69(0.37,1.30)	0.58
Prediabetes and diabetes												
Cases (%)	177(43.0)	204(49.4)	189(45.9)	191(46.2)	186(45.1)		156(37.9)	182(44.1)	206(50.0)	203(49.2)	200(48.5)	
Model 1[2]	1.00	1.27(0.97,1.67)	1.04(0.79,1.35)	1.00(0.74,1.34)	0.84(0.61,1.18)	.016	1.00	1.08(0.81,1.44)	1.26(0.93,1.69)	1.22(0.90,1.65)	1.11(0.82,1.51)	0.41
Model 2	1.00	1.31(1.00,1.72)	1.06(0.81,1.38)	1.01(0.76,1.36)	0.87(0.63,1.21)	0.21	1.00	1.06(0.80,1.42)	1.23(0.91,1.66)	1.19(0.88,1.62)	1.08(0.79,1.46)	0.52
Model 3	1.00	1.32(1.00,1.73)[*]	1.08(0.82,1.41)	1.04(0.77,1.40)	0.89(0.64,1.24)	0.28	1.00	1.05(0.78,1.39)	1.20(0.89,1.62)	1.15(0.84,1.56)	1.03(0.75,1.41)	0.75
Elevated blood pressure												
Cases (%)	192(46.6)	175(42.4)	197(47.8)	176(42.6)	214(51.9)		177(43.0)	189(45.8)	180(43.7)	204(49.4)	204(49.5)	
Model 1[2]	1.00	0.86(0.66,1.12)	0.98(0.75,1.28)	0.81(0.61,1.06)	1.20(0.87,1.67)	0.38	1.00	1.00(0.75,1.33)	0.82(0.60,1.11)	1.07(0.79,1.45)	1.00(0.72,1.39)	0.86
Model 2	1.00	0.86(0.66,1.12)	0.98(0.75,1.29)	0.81(0.62,1.07)	1.22(0.88,1.70)	0.34	1.00	1.01(0.76,1.34)	0.83(0.61,1.14)	1.08(0.80,1.47)	1.02(0.73,1.42)	0.79
Model 3	1.00	0.86(0.66,1.12)	0.98(0.75,1.29)	0.81(0.61,1.07)	1.22(0.87,1.70)	0.35	1.00	1.01(0.76,1.35)	0.83(0.61,1.14)	1.09(0.80,1.48)	1.02(0.73,1.44)	0.78
Low HDL-C												
Cases (%)	44(10.7)	40(9.7)	66(16)	60(14.5)	54(13.1)		44(10.7)	57(13.8)	51(12.4)	56(13.6)	56(13.6)	
Model 1[2]	1.00	0.84(0.54,1.31)	1.51(0.98,2.34)	1.31(0.85,2.02)	1.10(0.71,1.71)	0.29	1.00	1.29(0.84,1.99)	1.14(0.74,1.77)	1.21(0.76,1.94)	1.19(0.75,1.88)	0.63
Model 2	1.00	0.87(0.56,1.35)	1.56(1.01,2.41)[*]	1.36(0.88,2.10)	1.15(0.74,1.79)	0.22	1.00	1.30(0.84,2.01)	1.15(0.74,1.80)	1.23(0.77,1.97)	1.19(0.75,1.89)	0.61
Model 3	1.00	0.87(0.56,1.36)	1.61(1.05,2.47)[*]	1.41(0.91,2.18)	1.19(0.77,1.84)	0.16	1.00	1.28(0.83,1.98)	1.12(0.72,1.75)	1.19(0.75,1.89)	1.13(0.71,1.81)	0.78
High LDL-C												
Cases (%)	139(33.7)	130(31.5)	112(27.2)	102(24.7)	109(26.5)		128(31.1)	121(29.3)	123(29.9)	112(27.1)	108(26.2)	
Model 1[2]	**1.00**	**0.88(0.64,1.20)**	**0.70(0.50,0.97)**[*]	**0.63(0.45,0.88)**[**]	**0.65(0.47,0.92)**[*]	**<0.01**	**1.00**	**0.85(0.62,1.16)**	**0.83(0.62,1.13)**	**0.71(0.52,0.97)**[*]	**0.64(0.46,0.89)**[**]	**<0.01**
Model 2	**1.00**	**0.88(0.64,1.21)**	**0.70(0.50,0.97)**[*]	**0.63(0.45,0.88)**[**]	**0.66(0.47,0.93)**[*]	**<0.01**	**1.00**	**0.86(0.63,1.17)**	**0.85(0.63,1.15)**	**0.71(0.52,0.98)**[*]	**0.65(0.46,0.90)**[*]	**<0.01**
Model 3	**1.00**	**0.88(0.64,1.21)**	**0.69(0.50,0.96)**[*]	**0.62(0.44,0.87)**[**]	**0.65(0.46,0.92)**[*]	**<0.01**	**1.00**	**0.85(0.62,1.17)**	**0.84(0.62,1.14)**	**0.71(0.52,0.97)**[*]	**0.64(0.46,0.90)**[**]	**<0.01**
Elevated TAG												
Cases (%)	154(37.4)	145(35.1)	156(37.9)	152(36.8)	152(36.9)		136(33.0)	149(36.1)	162(39.3)	144(34.9)	168(40.8)	
Model 1[2]	1.00	0.86(0.64,1.16)	0.99(0.74,1.32)	0.98(0.74,1.31)	0.93(0.71,1.22)	0.91	1.00	1.15(0.86,1.54)	1.32(0.98,1.80)	1.05(0.78,1.42)	1.26(0.92,1.72)	0.27
Model 2	1.00	0.89(0.66,1.20)	1.02(0.76,1.36)	1.02(0.76,1.35)	0.97(0.74,1.28)	0.87	1.00	1.14(0.85,1.53)	1.31(0.96,1.77)	1.06(0.79,1.43)	1.24(0.90,1.70)	0.31
Model 3	1.00	0.89(0.66,1.20)	1.04(0.78,1.39)	1.05(0.79,1.40)	1.01(0.76,1.33)	0.66	1.00	1.12(0.83,1.51)	1.27(0.93,1.73)	1.02(0.75,1.38)	1.17(0.85,1.62)	0.35

Abbreviations: CM=cardiometabolic; CDQI=China dietary quality index; tAHEI=tailored Alternative Healthy Eating Index; Q=quintile; CHNS=China health and nutrition survey; HDL-C=high density lipoprotein-cholesterol; LDL-C=low density lipoprotein-cholesterol; TAG=triacylglycerol. [1] *P*-trend was calculated by assigning median values to quintiles of the China DQI score, and this variable was entered as a continuous term in the regression models. [2] Multivariable logistic regression models adjusted for age (18-<35y, 35-<50y and 50-65y), individual income (tertiles), education (less than primary, primary, and higher than primary), urbanicity index (tertiles) and geographic region (model 1), plus PA (tertiles), smoking status (current smoker, and former or never smoker), and hypertension history (model 2), additional TEI (continuous) (model 3).[*] $P < 0.050$, [**] $P < 0.010$, [***] $P < 0.001$

Table 3.6. OR (95% CI) of the prevalence of CM risk across the quintiles of the CDQI and tAHEI scores in Chinese women, respectively, CHNS

	CDQI scores					*P*-trend[1]	tAHEI scores					*P*-trend[1]
	Q1	Q2	Q3	Q4	Q5		Q1	Q2	Q3	Q4	Q5	
Diabetes												
Cases (%)	24(5.1)	29(6.1)	34(7.1)	28(5.9)	20(4.2)		21(4.4)	25(5.3)	31(6.5)	35(7.4)	23(4.8)	
Model 1[2]	1.00	1.15(0.64,2.05)	1.26(0.73,2.18)	1.11(0.60,2.06)	0.61(0.32,1.16)	0.13	1.00	1.13(0.59,2.17)	1.34(0.75,2.38)	1.32(0.73,2.37)	0.88(0.47,1.67)	0.79
Model 2	1.00	1.21(0.66,2.19)	1.28(0.73,2.24)	1.17(0.62,2.19)	0.62(0.32,1.18)	0.14	1.00	1.12(0.59,2.15)	1.34(0.75,2.39)	1.29(0.72,2.32)	0.88(0.47,1.67)	0.78
Model 3	1.00	1.22(0.67,2.23)	1.35(0.76,2.38)	1.26(0.67,2.38)	0.68(0.35,1.29)	0.27	1.00	1.06(0.55,2.04)	1.23(0.68,2.20)	1.10(0.60,2.01)	0.72(0.37,1.39)	0.31
Prediabetes and diabetes												
Cases (%)	187(39.4)	211(44.3)	242(50.8)	220(46.2)	235(49.5)		194(40.8)	203(42.6)	240(50.4)	241(50.6)	217(45.7)	
Model 1[2]	1.00	1.21(0.93,1.59)	1.48(1.13,1.94)**	1.21(0.89,1.63)	1.17(0.84,1.62)	0.43	1.00	0.97(0.72,1.31)	1.27(0.93,1.72)	1.15(0.86,1.54)	1.00(0.70,1.44)	0.73
Model 2	1.00	1.22(0.93,1.60)	1.49(1.13,1.96)**	1.20(0.89,1.63)	1.18(0.85,1.64)	0.40	1.00	0.96(0.71,1.30)	1.26(0.93,1.71)	1.14(0.85,1.53)	1.00(0.70,1.43)	0.75
Model 3	1.00	1.22(0.93,1.60)	1.49(1.13,1.96)**	1.20(0.88,1.64)	1.18(0.85,1.65)	0.41	1.00	0.97(0.72,1.30)	1.26(0.93,1.72)	1.15(0.85,1.54)	1.01(0.70,1.44)	0.73
Elevated blood pressure												
Cases (%)	162(34.1)	169(35.5)	178(37.4)	188(39.5)	183(38.5)		162(34.1)	157(33.0)	171(35.9)	193(40.5)	197(41.5)	
Model 1[2]	1.00	1.20(0.88,1.63)	1.14(0.84,1.56)	1.36(0.98,1.90)	1.17(0.82,1.69)	0.29	1.00	0.90(0.66,1.23)	1.00(0.74,1.36)	1.17(0.86,1.59)	1.28(0.94,1.75)	0.04
Model 2	1.00	1.20(0.88,1.63)	1.15(0.84,1.57)	1.36(0.98,1.89)	1.18(0.83,1.68)	0.27	1.00	0.89(0.65,1.22)	1.00(0.73,1.35)	1.15(0.85,1.56)	1.28(0.94,1.74)	0.03
Model 3	1.00	1.21(0.89,1.64)	1.16(0.84,1.58)	1.37(0.99,1.91)	1.19(0.84,1.70)	0.24	1.00	0.89(0.65,1.22)	1.00(0.74,1.35)	1.15(0.85,1.57)	1.28(0.93,1.76)	0.05
Low HDL-C												
Cases (%)		158(33.3)	162(34)	160(33.6)	170(35.7)			156(32.8)	175(36.8)	169(35.5)	164(34.5)	
Model 1[3]	1.00	1.03(0.80,1.33)	0.99(0.77,1.27)	1.09(0.85,1.41)	1.04(0.78,1.37)	0.70	1.00	1.15(0.89,1.50)	1.09(0.83,1.43)	1.02(0.77,1.35)	0.95(0.71,1.27)	0.48
Model 2	1.00	1.04(0.80,1.33)	0.99(0.77,1.28)	1.09(0.84,1.40)	1.05(0.79,1.38)	0.66	1.00	1.14(0.88,1.49)	1.09(0.83,1.42)	1.01(0.77,1.33)	0.94(0.71,1.25)	0.46
Model 3	1.00	1.01(0.79,1.30)	0.96(0.75,1.24)	1.04(0.80,1.34)	1.00(0.76,1.32)	0.94	1.00	1.18(0.91,1.53)	1.13(0.86,1.48)	1.08(0.82,1.43)	1.03(0.77,1.36)	0.89
High LDL-C												
Cases (%)	152(32.0)	156(32.8)	158(33.2)	137(28.8)	155(32.6)		168(35.4)	136(28.6)	140(29.4)	170(35.7)	144(30.3)	
Model 1[3]	1.00	1.04(0.78,1.40)	1.02(0.76,1.36)	0.87(0.62,1.22)	0.91(0.67,1.23)	0.32	1.00	0.67(0.50,0.90)**	0.70(0.52,0.94)*	0.89(0.65,1.21)	0.68(0.50,0.92)*	0.13
Model 2	1.00	1.04(0.78,1.40)	1.02(0.76,1.37)	0.87(0.62,1.21)	0.91(0.68,1.23)	0.32	1.00	0.67(0.50,0.89)**	0.70(0.52,0.93)*	0.87(0.64,1.20)	0.67(0.50,0.92)*	0.12
Model 3	1.00	1.04(0.77,1.40)	1.02(0.76,1.37)	0.86(0.61,1.22)	0.91(0.67,1.24)	0.33	1.00	0.66(0.49,0.89)**	0.69(0.52,0.93)*	0.87(0.63,1.18)	0.67(0.49,0.91)**	0.10
Elevated TAG												
Cases (%)	122(25.7)	151(31.7)	151(31.7)	129(27.1)	158(33.3)		140(29.5)	148(31.1)	141(29.6)	141(29.6)	141(29.7)	
Model 1[3]	**1.00**	**1.39(1.01,1.90)***	**1.37(1.01,1.86)***	**1.15(0.83,1.59)**	**1.48(1.06,2.07)***	**0.09**	1.00	1.06(0.81,1.39)	1.01(0.76,1.34)	0.97(0.73,1.30)	0.99(0.72,1.35)	0.77
Model 2	**1.00**	**1.43(1.04,1.96)***	**1.39(1.02,1.90)***	**1.15(0.83,1.60)**	**1.52(1.09,2.13)***	**0.08**	1.00	1.05(0.80,1.36)	1.00(0.76,1.32)	0.95(0.71,1.27)	0.98(0.72,1.33)	0.72
Model 3	**1.00**	**1.42(1.04,1.95)***	**1.38(1.01,1.88)***	**1.14(0.82,1.59)**	**1.51(1.08,2.11)***	**0.09**	1.00	1.05(0.81,1.37)	1.01(0.76,1.33)	0.96(0.72,1.29)	1.00(0.73,1.36)	0.83

Abbreviations: CM=cardiometabolic; CDQI=China dietary quality index; tAHEI=tailored Alternative Healthy Eating Index; Q=quintile; CHNS=China health and nutrition survey; HDL-C=high density lipoprotein-cholesterol; LDL-C=low density lipoprotein-cholesterol; TAG=triacylglycerol. [1] *P*-trend was calculated by assigning median values to quintiles of the tAHEI score, and this variable was entered as a continuous term in the regression models. [2] Multivariable logistic regression models adjusted for age (18-<35y, 35-<50y and 50-65y), individual income (tertiles), education (less than primary, primary, and higher than primary), urbanicity index (tertiles) and geographic region (model 1), plus PA (tertiles), smoking status (current smoker, and former or never smoker), and hypertension history (model 2), additional TEI (continuous) (model 3). *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

Supplemental Table 3.1. Energy-level food intake recommended by the 2007 Chinese Dietary Guidelines [38]

Energy-level [a]	1800kcal	2200kcal	2400kcal	2600kcal
Coarse grain, g/d	75	75	75	75
Soybean and nuts, g/d	30	40	40	50
Vegetable, g/d	300	400	450	500
Fruit, g/d	200	300	400	400
Red meat and poultry, g/d	50	75	75	75
Milk and products, g/d	300	300	300	300
Seafood, g/d	50	75	75	100
Edible oil, g/d	25	25	30	30
Salt, g/d	6	6	6	6

[a] Based on the Chinese Dietary Recommendation Intakes[58], energy-level=2600kcal and 2400kcal for men and women aged 18 to 50, respectively; energy-level=2400kcal and 2200kcal for men and women aged 50 to 60, respectively; energy-level=2200kcal and 1800kcal for men and women aged 60 to 65, respectively.

Supplemental Table 3.2. Nutrient composition according to sex-specific quintiles of the CDQI and tAHEI scores, respectively, CHNS[1]

	CDQI scores					*P*-trend[1]	tAHEI scores					*P*-trend
	Q1	Q2	Q3	Q4	Q5		Q1	Q2	Q3	Q4	Q5	
Men												
Energy(kcal)	**2807.0±37.4**	**2733.9±40.2**	**2576.4±36.3**	**2539.5±36.6**	**2499.1±37.2**	**<0.001**	**2426.8±35.6**	**2557.0±35.7**	**2624.1±38.4**	**2741.3±38.1**	**2806.8±39.3**	**<0.001**
Carbohydrate(g)	327.3±5.6	349.6±6.2	349.1±6.0	369.5±6.7	369.4±7.0	<0.001	332.4±5.7	353.8±6.2	357.8±6.7	363.7±6.6	357.3±6.5	<0.01
Fiber(g)	11.6±0.4	13.1±0.5	12.4±0.4	13.9±0.4	14.8±0.4	<0.001	**9.8±0.3**	**12.0±0.3**	**13.9±0.5**	**14.3±0.4**	**15.7±0.4**	**<0.001**
Protein(g)	72.6±1.1	78.1±1.3	75.0±1.2	77.6±1.3	81.6±1.5	<0.001	**65.4±1.1**	**73.0±1.1**	**76.1±1.2**	**81.7±1.4**	**88.6±1.4**	**<0.01**
Fat(g)	**113.5±2.3**	**99.8±2.5**	**87.9±2.4**	**76.9±2.1**	**72.9±1.8**	**<0.001**	**82.7±2.3**	**85.0±2.1**	**88.1±2.5**	**94.4±2.5**	**100.8±2.4**	**<0.001**
% of energy from fat	**36.2±0.5**	**32.4±0.7**	**30.4±0.7**	**27.4±0.7**	**26.2±0.5**	**<0.001**	**29.9±0.6**	**30.0±0.7**	**30.1±0.7**	**30.7±0.7**	**31.9±0.5**	**0.02**
Cholesterol(mg)	302.4±12.3	304.2±13.3	285.8±15.9	268.3±12.3	325.2±15.6	0.07	249.7±10.2	269.9±11.6	277.8±12.0	317.8±18.1	370.6±15.6	<0.001
Vitamin A(μg)	446.1±28.7	486.6±40.5	467.2±25.1	454.4±23.7	454.8±20.5	0.43	506.2±42.7	432.4±23.2	446.3±28.0	444.3±21.8	480.0±21.3	0.12
Carotene(mg)	1757.1±102.1	1902.6±96.8	1933.6±94.4	1980.0±112.8	1885.2±86.4	0.02	2055.3±110.4	1851.5±99.8	1805.5±92.0	1739.8±71.7	2007.1±114.2	<0.001
Vitamin C(mg)	**81.3±2.7**	**83.5±2.7**	**86.5±2.3**	**95.2±2.9**	**100.3±3.2**	**<0.001**	76.6±2.5	82.3±2.6	89.7±2.9	92.1±2.6	106.0±3.3	0.13
Vitamin E(mg)	37.3±1.3	36.3±1.5	33.5±1.1	36.5±1.2	37.1±1.1	<0.001	**23.8±1.0**	**30.2±1.3**	**36.2±1.1**	**41.0±1.2**	**49.6±1.3**	**0.04**
Potassium(mg)	1676.8±31.1	1851.9±38.3	1823.6±31.8	1987.5±36.7	2159.9±40.3	<0.001	**1538.3±31.4**	**1766.8±31.7**	**1911.7±33.8**	**2013.1±33.1**	**2269.9±42.2**	**<0.001**
Sodium(mg)	**7261.4±200.3**	**6519.9±209**	**5721.8±171.7**	**5135.1±164.9**	**4183.6±116.4**	**<0.001**	5798.9±161.6	5790.1±160.3	6207.7±210.8	5738.7±186.4	5286.8±189.6	<0.001
Calcium(mg)	**370.6±9.6**	**410.6±11.1**	**421.2±10.3**	**438.9±11.9**	**500.1±11.8**	**<0.001**	**303.0±7.6**	**397.4±11.7**	**421.8±10.3**	**467±10.1**	**552.1±11.8**	**<0.001**
Iron(mg)	24.1±0.5	25.2±0.5	24.1±0.5	25.2±0.6	26.3±0.7	<0.001	**21.4±0.5**	**23.8±0.4**	**25.2±0.5**	**26.0±0.5**	**28.4±0.8**	**<0.001**
Zinc(mg)	12.5±0.2	12.8±0.2	12.4±0.2	12.6±0.2	12.9±0.2	<0.001	**11.8±0.2**	**12.4±0.2**	**12.4±0.2**	**12.9±0.2**	**13.7±0.2**	**<0.001**
Phosphorus(mg)	1047.2±15.9	1125.9±18.9	1101.1±17.6	1154.5±19.2	1205.4±20.6	<0.001	**940.9±15.3**	**1075.8±16.5**	**1135.3±18.3**	**1201.0±18.8**	**1281.0±19.7**	**<0.001**
Selenium(mg)	47.4±1.4	53.2±1.7	47.0±1.1	48.1±1.1	52.8±1.4	<0.001	40.4±1.0	46.7±1.0	51.5±1.8	51.9±1.3	58.1±1.3	0.58

Supplemental Table 3.2. Nutrient composition according to sex-specific quintiles of the CDQI and tAHEI scores, respectively, CHNS[1](continued)

	CDQI scores					*P*-trend[1]	tAHEI scores					*P*-trend
	Q1	Q2	Q3	Q4	Q5		Q1	Q2	Q3	Q4	Q5	
Women												
Energy(kcal)	**2391.8±30.8**	**2264.9±31.3**	**2207±29.6**	**2122.9±29**	**2084.6±29.7**	**<0.001**	**2069.2±27.5**	**2159.6±28.4**	**2180.2±28.3**	**2293±32.6**	**2369.1±33.3**	**<0.001**
Carbohydrate(g)	299.1±5.1	307.7±5.3	307.7±5.1	317.9±5.9	304.5±5.3	<0.001	293.9±4.9	302.4±5.0	309.7±5.6	318.1±5.7	312.7±5.4	<0.001
Fiber(g)	**10.0±0.3**	**11.3±0.4**	**11.7±0.3**	**12.6±0.3**	**13.7±0.3**	**<0.001**	**8.8±0.2**	**10.5±0.3**	**12.1±0.3**	**13.0±0.3**	**14.9±0.4**	**<0.001**
Protein(g)	63.0±1.0	66.0±1.1	65.5±1.0	66.2±1.1	70.4±1.2	<0.001	**56.8±0.9**	**60.4±0.9**	**64.8±1.0**	**71.6±1.1**	**77.6±1.3**	**<0.001**
Fat(g)	**99.6±2.2**	**81.2±2.0**	**75.6±2.1**	**62.6±1.6**	**62.1±1.5**	**<0.001**	70.7±1.9	74.1±1.9	72.3±1.9	76.7±2.0	87.4±2.3	<0.001
% of energy from fat	37.0±0.5	32.0±0.6	30.4±0.6	27.0±0.6	26.7±0.5	<0.001	30.2±0.7	30.4±0.5	29.9±0.7	29.7±0.5	32.9±0.6	<0.01
Cholesterol(mg)	250.0±10.2	263.9±11.0	254.7±11.7	225.8±9.3	271.3±10.6	0.04	**213.1±8.3**	**225.8±10.4**	**243.9±11.2**	**277.4±10.8**	**305.4±11.5**	**<0.001**
Vitamin A(μg)	400.6±25.4	406.4±22.7	426.8±27.4	421.2±21.7	420.9±19.8	0.02	413.7±26.2	390.1±26.8	367.2±16.7	428.6±24.5	476.3±21.8	0.09
Carotene(mg)	1593.2±81.1	1632.7±72.7	1825±141.1	1803.8±74.1	1929.5±114.2	<0.001	1705.2±83.9	1723.5±140.4	1598.5±72	1668.5±73.3	2089.1±113.4	<0.001
Vitamin C(mg)	**74.3±2.1**	**80.1±2.4**	**82.5±2.3**	**84.5±2.5**	**105.0±3.6**	**<0.001**	72.6±2.1	74.5±2.0	81.1±2.5	89.3±2.6	109.0±3.5	0.45
Vitamin E(mg)	34.2±1.2	29.8±1.0	30.4±1.0	29.8±0.9	32.7±0.8	<0.01	20.6±0.8	27.1±0.9	30.6±0.9	34.7±0.9	43.8±1.2	0.23
Potassium(mg)	**1457.4±24.3**	**1590.2±29.4**	**1667.5±26.7**	**1729.5±28.3**	**1991.1±39.4**	**<0.001**	**1387.7±23.7**	**1504.3±26.2**	**1679.3±34.4**	**1787.8±25.7**	**2076.6±34**	**<0.001**
Sodium(mg)	**6715.6±178.1**	**5721.4±186.1**	**4973.2±154.1**	**4744.5±177**	**3873.5±139.2**	**<0.001**	5130.9±135	5033.3±136.3	5253.4±142.7	5647.4±238.4	4962.1±189.3	<0.001
Calcium(mg)	**308.0±6.3**	**361.8±8.8**	**373.0±8.6**	**392.2±8.5**	**460.4±12.8**	**<0.001**	**268.6±5.7**	**322.8±7.4**	**377.3±10.3**	**429.1±8.6**	**497.4±11**	<0.001
Iron(mg)	**20.8±0.3**	**21.3±0.4**	**21.6±0.4**	**22.2±0.5**	**22.5±0.5**	**<0.001**	**18.6±0.3**	**20.1±0.4**	**21.8±0.5**	**23.3±0.4**	**24.5±0.5**	<0.001
Zinc(mg)	10.8±0.2	11.0±0.2	10.8±0.2	10.7±0.2	11.0±0.2	<0.001	**10.3±0.2**	**10.4±0.2**	**10.5±0.2**	**11.1±0.2**	**11.9±0.2**	<0.001
Phosphorus(mg)	**908.4±13.4**	**969.0±15.8**	**969.5±14.4**	**985.4±15.2**	**1047.0±17.8**	**<0.001**	**829.6±11.9**	**894.7±13.3**	**964.5±14.2**	**1061.1±15.9**	**1129.4±17.4**	<0.001
Selenium(mg)	38.9±0.8	42.3±1.3	42.0±0.9	41.0±1.0	45.7±1.3	<0.001	34.6±0.7	38.7±0.9	41.8±1.2	44.1±0.9	50.9±1.4	0.07

Abbreviations: CDQI=China dietary quality index; tAHEI=tailored Alternative Healthy Eating Index; Q=quintile. Mean ±SE (all such values);[1] General linear model was used to test trends. *P*-trend was calculated by assigning median values to quintiles of each score and this variable was entered as a continuous term in the regression models.

CHAPTER 4: SOCIODEMOGRAPHIC DISPARITY IN THE DIET QUALITY TRANSITION AMONG ADULTS IN CHINA, 1991 TO 2011

Overviews

This study investigates secular trends in diet quality distribution and related socioeconomic disparity from 1991 to 2011 in the Chinese adult population. The current analysis uses the 1991–2011 China Health and Nutrition Survey data on 13,853 participants (6,876 men; 6,977 women) ages 18 to 65 with an average of 4.1responses for each subject (56,319 responses). Dietary intake assessment was carried out over a 3-day period with 24-hour recalls and a household food inventory. We used LMS method [the L curve (Yeo-Johnson to remove skewness), M curve (median) and S curve (coefficient of variation)] to present gender-specific distribution characteristics of the tailored Alternative Healthy Eating Index (tAHEI), created from Harvard AHEI-2010, to measure overall diet quality and performed quantile regression models to investigate shifts in tAHEI scores at different percentiles and used mixed-effect linear regression to examine mean diet quality transition and related sociodemographic disparity. Results showed that 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 ($p < 0.001$). The whole distribution of the tAHEI score shifted rightward and became flatter between 1991 and 2011 for men and between 2006 and 2011 for women. The adjusted tAHEI component score increased by 6.8 (6.6, 7.0) points in men and 7.0 (6.9, 7.2) points in women for polyunsaturated fatty acids (PUFAs) and 5.3 (5.2, 5.4) points in men and 5.3 (5.2, 5.5) in women for long chain ((ω-3) fats over the 21-year period.

Moreover, increases in the total scores occurred across the entire distribution, with greater increases occurring at upper percentiles than lower percentiles and with larger increase from 2009 to 2011. In addition, diet quality transition varied significantly across sociodemographic groups. The gaps in diet quality between northern and southern adults widened, while the gaps across income, education and urbanicity narrowed over 20-year period. Our findings suggest that intervention and policy to improve diet quality should give priority to adults with poorer diet quality who tend to have lower incomes and living in communities with lower degrees of urbanicity or southern provinces in China.

Introduction

The World Health Organization reports that diet, alcohol consumption, smoking, and 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 [10, 11] and PA [12, 13] along with its rapid economic growth and social changes and the concurrent shifts in disease patterns [11]. China's food intake 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 [10, 11, 1410, 11, 14.] Pork, especially fatty fresh pork, is the most predominant animal-source food consumed in China[10, 15]. Considering the multiple dimensions of the changes in the Chinese diet, the key issue is how to capture the dynamic complexity and assess trends in the overall diet across time.

Diet quality indexes developed from current healthy diet recommendations, have gained increasing attention for assessing overall diet quality and accounting for potential interaction across many foods or nutrients. Moreover, diet indexes allow 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, 21, 51]. The Alternative Healthy Eating Index (AHEI) [30] and its most recent version, AHEI-2010 assess adherence to the HEP and have strongly predicted major chronic disease in many Western populations [9, 17-20]. One recent nationally representative study in the United States showed a steady improvement in that population's AHEI-2010 scores between 1999 and 2010, but the overall diet quality remained poor, especially in lower socioeconomic status (SES) groups[73].

In China, the majority of previous studies have generally focused on trends in mean intake of nutrients, intake of specific foods or food groups and sociodemographic role, no study to date has investigated secular trends in the overall diet quality in Chinese population and whether secular trends are different in sociodemographic groups.

The present study aimed to examine long-term Chinese diet quality transition and the role that sociodemographic characteristics play in the transition. We therefore applied the tailored AHEI-2010 (tAHEI)[74] to assess overall diet quality and used longitudinal quantile regression to estimate trends in percentiles of diet quality and socioeconomic influence among adults ages 18 to 65 in China for the period 1991 to 2011 of the China Health and Nutrition Survey (CHNS).

Methods

Study Population

All data used in this study were derived from the CHNS, an ongoing longitudinal study. Initiated in 1989, the CHNS 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[20, 53]. 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 individuals in each household were surveyed for all data in each wave. The sampling procedure has been described in detail elsewhere[21, 53]. Such sampling reflects the nature of panel data: multiple measurement occasions (level 1) for individuals (level 2) nested in communities (level 3).

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 ages 20 to 45 were involved in 1989. Of all 18- to 65-year-old participants who had complete socioeconomic and dietary data, we excluded women currently pregnant or lactating during a survey year and those having implausible energy intakes (< 800 kilocalories [kcal] per day or > 6,000 kcal for men and < 600 kcal or > 4,000 kcal for women) [75]. We also excluded participants with only one wave of data. Our final sample included 13,853 participants (6,876 men; 6,977 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-hour dietary recalls 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 (SSBs) and fruit juices since 2004 and alcohol consumption since 1993. The dietary data collection details have been described elsewhere[54, 76] .

We used the tAHEI, tailored from the Harvard AHEI-2010[27], to assess diet quality. The tailoring methods are described in detail elsewhere [74]. In general, major tailoring includes: (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 juices intake from the past year FFQ in available survey years to reduce the potential underestimation of 24 h recall due to episodically consumption; (3) replaced the whole grain component with cereal fiber component due to extremely low intake and lack of variation in Chinese adults; (4) scaled 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 64g [13]; (5) linked all Chinese foods to the US Food and Drug Administration (USDA) Food and Nutrient Database for Dietary Studies (FNDDS) [56] and National Nutrient Database for Standard Reference [57] to estimate polyunsaturated fatty acid (PUFA) and long chain (ω-3) fatty acid intake; (6) omitted *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). **Table 4.1** illustrates the components and scaling methods of the tAHEI. We used the three-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.

Assessment of Demographic and Socioeconomic 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[65]. We categorized the continuous urbanicity index into wave-specific tertiles. We also included the geographic regions (northern, central, and southern) due to the different dietary intakes shown in previous studies[52, 66] .

Statistical Analysis

We first present descriptive statistics (means, standard deviations, and frequencies when appropriate) on socioeconomic factors of interest stratified by sex for adults by survey years. We used chi-square 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)][77] 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 [78, 79] 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 [39] to estimate average secular trend of the total tAHEI scores and each component score, adjusting for all the covariates. In aforementioned models we included baseline age as continuous and modeled survey years as dummy variables rather than continuous, given potentially uneven changes over time.

Lastly, 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 socio-demographic 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 the XTMIXED programs in Stata/SE (Intercooled STATA, version 12.0, StataCorp, College Station, TX plotted density and quantile distribution using the VGAM package, and performed longitudinal quantile regression models using the LQMM package in R version 2.15.1 (R development Core Team, Vienna, Austria). For all other descriptive analyses, we used SAS 9.3 (SAS Institute, Cary, NC).

Results

As shown in **Table 4.2**, 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 increase 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

Supplemental Table 4.1 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 the degree of increase in unadjusted tAHEI score was uneven, with upper percentile score having larger rate of increase than lower percentile. The increase in the 95th percentile from 1991 to 2011 was around 18.4 points in men and 14.8 points in women, whereas the increase for the median was 13.6 and 11.6 and for the 10th percentile 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 (**Figure 4.1**). 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 4. 3** and **Table 4.4**, 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 than the mean estimate of secular trends for both sexes.

For men, after additionally adjustment for income and education (model 2), only the 25th percentile estimates in 2011 as compared to 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 4.2 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 4.5 presents predicted mean of the tAHEI score across demographic and socioeconomic factors from a fully adjusted mixed-effect linear regression. **Figure 4.3** 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 for both sexes, but with higher diet quality due to slightly larger increase than lower urbanicity after 2004. 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.

Discussion

In this analysis using data from the CHNS between 1991 and 2011, we illustrate strong and differential shifts in the overall diet quality distribution in Chinese adults. Along with confirming that the overall quality of the Chinese diet had improved across the entire distribution of the tAHEI scores, we show that the diet quality transition appeared to vary greatly among different score percentiles and that adults with higher diet quality tended to have larger improvement than those with lower diet quality over time. The most remarkable improvement across diet quality distribution occurred between 2009 and 2011, which are mostly attributable to increased intakes of PUFAs, EPA and DHA. In addition, improvements in the overall diet quality were observed in all sociodemographic groups despite sociodemographic disparity in diet quality transition.

Limited studies have used the AHEI-2010 to assess diet quality and/or to examine longitudinal trends. One previous study found that the mean baseline AHEI-score in 81,757 of female nurse aged 30–55 y was 47.6 ± 10.8 (including *trans* fat component score: about 6.0 points) in 1984 and the mean AHEI-score in 51,529 U.S. healthy professional men aged 40–75 y was 52.4 ±11.5 (including *trans* fat component score: about 7.8 points) in 1986 [27]. One recent study in nationally representative sample of 29 124 US adults aged 20 to 85 years indicated increased energy-adjusted AHEI-2010 scores without the *trans* fat component from 34.2 (33.1–35.2) in 1999 to 2000 to 37.1 (36.6–37.7) in 2009 to 2010 [73]. We observed an increase of 11.3 points for Chinese men and women ages 18 to 65 between 2000 and 2011. It seems that Chinese adults have better diet quality and gained larger improvement in diet quality than US adults in the past decade. However, in making these comparisons, it is important to note that the tAHEI was not identical to AHEI-2010 due to several aspect of tailoring, different study design and sociodemographic characteristics of study population; all of which may explain the differences between studies.

We also found different improvement profile of diet quality over time in Chinese adults as compared to that in US adults. These included a remarkable increase in PUFAs score (about 7.0 points) and long chain (ω-3) fatty acids score (about 5.3 points) in the tAHEI score among Chinese adults between 2009 and 2011, slight increase in whole fruit score and nuts and legume score by about 1.0 points, and slight decline in cereal fiber score, SSB score and red meat score over time. In contrast, there was slight increase in SSB and fruit juice score (0.9 points), whole fruit score (0.7 points), whole grains (0.5 points) and nuts and legumes score (0.4 points) and slight decrease in sodium score in AHEI-2010 without *trans* fat among US adults over 12-year period[73]. Several studies suggested significant increase in the intake of edible oils rich in PUFAs[10, 80] and sea foods rich in long chain (ω-3) fatty acids[10, 15] in the past two decades.

Previous studies using the CHNS data examined the role of sociodemographic characteristics for changes in specific nutrients, foods or food groups. Du, S et al found that income level was negatively associated with intake of flour and rice and products and positively with intake of animal-source foods and edible oils among 5783 Chinese adults ages 20 to 45 from 1989 to 1997[80]. Two studies from the 2002 National Nutrition Survey in China showed consistently positive associations of income level with excessive intakes of animal-source foods and edible oils and percentage of energy from dietary fat [81, 82]. Zhai et al. suggested that higher urbanicity was associated with higher intake of total animal-source foods and lower intake of coarse grains in adults ages 18 to 59 years from 1991 to 2011[10]. Our results add valuable information on sociodemographic disparity in Chinese diet quality transition. We found significant improvements in diet quality in all sociodemographic subpopulations over time, however, diet quality transition varied across income, education, urbanicity and geographic regions. We found wider gaps in overall diet quality between southern and northern adults over the 21-year period. Adults living in high-urbanized communities shifts from lowest to highest diet quality since 2004 due to larger increase during follow-up. Men with medium income and education had the best diet quality and gaps across subgroups narrowed, whereas women's diet quality was not significantly different across income and education level. In contrast, US adults show different socioeconomic disparities in diet quality. Wang and colleague found that higher socioeconomic status adults had greater improvement in diet quality, assessed by AHEI-2010, and the gaps in diet quality between higher and lower SES adults widen over 12-year period of time[73, 83].

Our findings have important health implications. Diet, together with physical activity, alcohol consumption, and smoking, are modifiable risk factors for the increasing chronic disease epidemic worldwide [1]. Our study evaluated diet as a whole accounting for alcohol consumption to capture the complexity of diet shifts. We found limited improvement in adults with poor diet quality and the rapid shifts period between 2009 and 2011. Moreover, sociodemographic disparity in diet quality transition is a public health concern. Increased gaps across geographic regions differential role of degree of urbanicity in diet quality since 2004 and decreasing impact of income and education on diet quality provide insight into future nutrition intervention and policy priority to combat chronic disease epidemic and subsequently increasing disease burden in China.

Strengths

Our study is the first to investigate secular trends in diet quality distribution in a large longitudinal sample with four repeated measurements over a 21-year period using the tAHEI in a country undergoing rapid transitions. We used a single diet index score to assess diet quality. Many previous studies reported shifts in mean intake of specific nutrients, foods or food groups over time[10, 14, 15, 80, 84]. Diet quality analysis is the most appropriate way to capture the dietary complexity of multidimensional changes in consumption of food groups and may very well represent the synergistic effect of foods on health outcomes [20, 85]. Index-based measurement has been developed from the current evidence-based dietary recommendations, and higher index scores imply higher diet quality[9]. Therefore, the use of tAHEI was a simple and practical way to standardize and track diet quality transitions across the survey years.

The longitudinal quantile analysis we used is well suited for studies of changes in distribution. This method handles skewed distribution, is not sensitive to outliers, accounts for repeated measurements, and can provide more precise and robust estimates in comparison with traditional linear regressions. In addition, quantile analysis can provide multiple estimates to reflect characteristics of distribution transition and sociodemographic role across the whole distribution, whereas mixed-effect linear regression can only provide one estimate to assess population mean status. Finally, survey years modeled as dummy variables contribute to discovering the uneven degree of diet quality transition over time instead of a continuous coding to only present average changes per year.

Limitations

Our study has several limitations. First, the tAHEI was tailored to match Chinese dietary data and therefore was not identical to the AHEI-2010. Such tailoring may not reflect the nature of the AHEI-2010 as a measure of overall diet quality. For example, we may have underestimated cereal fiber intake due to limited insoluble fiber in China FCT. Fatty acid composition may be different due to country-specific food types and planting conditions. One recent study suggested that decreased trans fatty acid consumption accounted for more than half of the improvement in the overall AHEI-2010 scores[73]. Despite the lack of trans fatty acid information in the China FCT, the rapid increase in the intake of edible oils [10, 46] as the major source of trans fatty acid in Chinese adults [86] may be an important dimension of overall diet quality. As for the definition of whole grains, Mozaffarian et al. defined the most healthful whole grains as a ratio of less than 10:1 total carbohydrate to fiber[59, 87] . However, very minimal cereal fiber is consumed in China, which satisfies this definition, given that highly refined wheat, rice, or wheat- or rice-based products make up the majority of the cereal consumed in China. Therefore, it would be beneficial to build fatty acid (including *trans* fat) and whole grain databases into the China FCT and to reassess diet quality using evaluations relatively identical to the AHEI-2010. In addition, the tAHEI does not account for cooking methods or eating behaviors, which also plays important roles in overall diet quality and related health outcomes. Previous studies using the CHNS reported a marked increase in the proportion of energy from deep-fried and stir-fried foods during the period we studied[10, 88] .

In conclusion, Chinese adults gained the most significant improvements in the overall quality across the whole distribution between 1991 and 2011. However, Chinese diet quality is still far from optimal (about 50.0points out of 100 full points) despite significant improvement. Unlike what has been seen in other high-income countries, in China, individuals with lower incomes and who live in lower urbanized communities had lower dietary quality and less improvement over time. From the perspective of public health, nutrition intervention and policy efforts, low income and lower urbanized subpopulations should be given priority at this time in order to reduce the burden of non-communicable disease.

Tables and Figures

Table 4.1. Tailoring method of the Harvard AHEI-2010

Components	Criteria for minimum score(0) [1]	Criteria for maximum score(10) [1]	Comments on tailoring
Vegetables, g/d [2]	0	≥591	5 servings/d (1 serving is 0.5 cup of vegetables)
Whole fruit, g/d [2]	0	≥473	4 servings/d (1 serving is 0.5 cup of berries)
Cereal fiber, g/d [2]	0	15	15 g cereal fiber as ideal on the basis of epidemiologic studies and the distribution in our cohorts.
Nuts and legumes, g/d [2]	0	28	1 serving/d was considered to be ideal on the basis of the AHEI recommendations and the current literature. One serving is 1 oz of nuts or 1 tablespoon (15 ml) of peanut butter. *
Long-chain (n-3) fats (EPA+DHA), mg/d [3]	0	250	The cutoff for optimal intake (250 mg/d) is about 100g/d of fish
PUFA, % of energy [3]	≤2	≥10	The highest score was given to individuals with 10% of total energy intake from PUFA. PUFA does not include EPA or DHA intake *
Red/processed meat, g/d [2]	≥170 (red meat)	0	An upper limit of 1.5 servings/d (1 serving is 4 oz of unprocessed meat or 1.5 oz of processed meat) *
Sodium, mg/d	Highest decile	Lowest decile	The cutoffs for sodium were based on deciles of distribution in the study population. This method is used by the AHEI-2010 due to lack of brand specificity in the FFQ to accurately estimate absolute intake.
SSB and fruit juice, g/d [2]	≥227	0	≥1 serving/d was considered to be the least optimal. 1 serving is 8 oz. We use the past year FFQ of SSB and fruit juice, instead of 3 consecutive 24 hour recall, to get more precise estimate of daily intake for episodically consumed SSB and fruit juice.
Alcohol, drinks/d [4]			
Women	≥2.5	0.5-1.5 (0-<0.5, score = 2.5)	One drink is 4 oz of wine, 12 oz of beer, or 1.5 oz of liquor. For both men and women with alcohol intake less than 0.5 including zero, we score this component 2.5 points.
Men	≥3.5	0.5-2.0 (0-<0.5, score = 2.5)	
Trans fat, % of energy	---	---	We omitted trans fat component in the tailored AHEI-2010 given a lack of information on trans fat composition of all eaten food in both China and USDA FCT.
Total score	0	100	

Abbreviations: AHEI=Alternative Healthy Eating Index; CHNS= China Health and Nutrition Survey; DHA= Docosahexenoic acid; EPA= Eicosapntemacnioc Acid; FNDDS=Food and Nutrient Database for Dietary Studies; HEP=Healthy Eating Pyramid; PUFA=polyunsaturated fatty acid; SR=standard references; SSB=sugar-sweetened beverages. [1] Intermediate intakes were scored between the minimum and the maximum according to the formula: component score= (Maximum score / $(A_{max}-A_{min})$)*$(X-A_{min})$ for adequacy components; component score = Maximum score - maximum score / $(A_{max}-A_{min})$)*$(X-A_{min})$ for moderate components (red/processed meat, sodium, SSB and fruit juice, and alcohol); A_{max} is maximum amount of the component corresponding to the recommended intake, while A_{min} is minimum amount of the component corresponding to the recommended intake. X: amount consumed by the individual. [2] Serving units were transferred to grams to match the CHNS diet data. (1 cup = 236.59 g; 1 oz = 28.35 g); [3] We additionally linked all Chinese FCT foods to the USDA FNDDS and SR nutrient databases to estimate fatty acid composition which is unavailable from the China FCT. [4] Grams units were transferred to drinks for alcohol component.

Table 4.2. 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	3,210	3,473	3,608	3,998	3,578	3,496	3,493	3,063	3,342	3,581	3,530	3,967	3,632	3,634	3,544	3,170
Energy-adjusted tAHEI score [a]*	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]*	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 tertiles [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 (%)*																
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 tertiles [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 (%)*																
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] Median values by survey year-specific tertiles;*Statistically significant difference among survey years based on chi-square tests, analysis of variance tests or nonparametric median test for median of tertiles, $p < 0.05$.

Table 4.3. Quantile regression results for 25th, 50th, 75th, 85th, and 95th percentiles versus mixed-effect regression results 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 baseline age (model 1), plus individual income (tertiles) and education (less than primary, primary, and higher than primary) (model 2), additional urbanicity index (tertiles) and geographic region (model3). *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 4.4. Quantile regression results for 25th, 50th, 75th, 85th, and 95th percentiles versus mixed-effect regression results 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 baseline age (model 1), plus individual income (tertiles) and education (less than primary, primary, and higher than primary) (model 2), additional urbanicity index (tertiles) and geographic region (model3). *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 4.5. 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)

Table 4.5. Predicted tAHEI score by demographic and socioeconomic factors, CHNS, 1991-2011 (continued)

Characteristic	1991	1993	1997	2000	2004	2006	2009	2011
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)

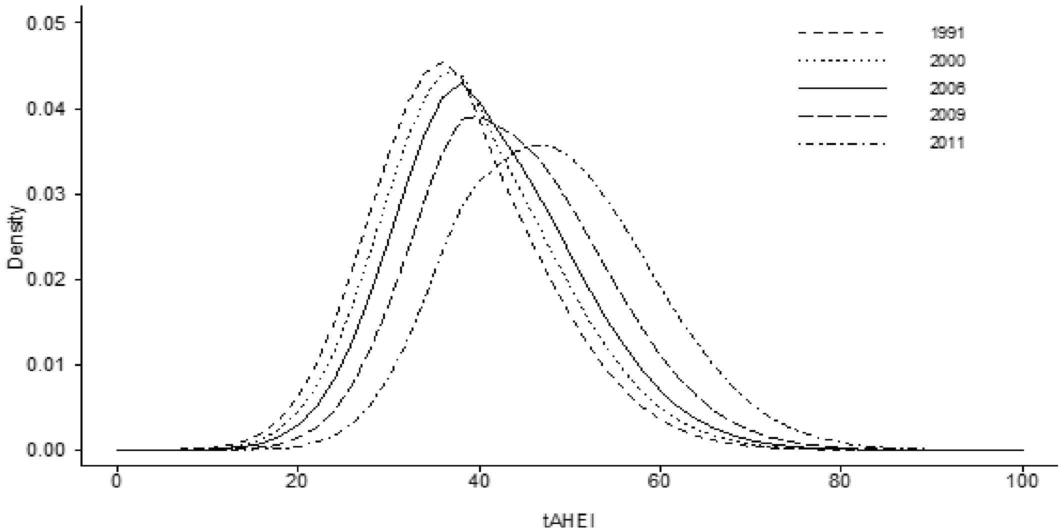
Abbreviations: CHNS, China Health and Nutrition Survey; tAHEI, tailored Alternative Healthy Eating Index.

[a] Values are predicted margins (standard error) estimated by mix-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.

Supplemental Table 4.1. Distribution and mean (95% CI) of the unadjusted tAHEI scores among adult men and women in the CHNS, 1991–2011

	10th percentile	25th percentile	50th percentile	75th percentile	90th percentile	95th percentile	Mean
Men							
1991	27.0 (26.3, 27.5)	31.8 (31.4, 32.2)	36.9 (36.4, 37.1)	42.0 (41.6, 42.4)	46.8 (46.3, 47.3)	50.0 (49.4, 50.7)	37.0 (36.6, 37.3)
1993	27.6 (27.0, 28.0)	32.9 (32.4, 33.3)	39.0 (38.6, 39.6)	45.2 (44.9, 45.8)	51.0 (50.5, 51.5)	54.8 (53.8, 55.5)	39.3 (39.0, 39.6)
1997	28.7 (28.4, 29.1)	33.3 (33.0, 33.8)	38.6 (38.2, 39.0)	44.9 (44.4, 45.2)	50.4 (49.9, 51.1)	53.8 (53.4, 54.5)	39.2 (38.9, 39.6)
2000	27.5 (27.1, 28.0)	32.5 (32.2, 32.8)	38.3 (38.0, 38.7)	44.6 (44.2, 45.0)	50.7 (50.2, 51.2)	54.9 (54.0, 55.7)	38.8 (38.5, 39.1)
2004	27.8 (27.4, 28.3)	33.4 (32.9, 33.7)	39.5 (39.1, 39.9)	46.9 (46.3, 47.4)	54.1 (53.6, 54.8)	58.2 (57.6, 58.7)	40.4 (40.1, 40.7)
2006	28.8 (28.4, 29.0)	33.9 (33.5, 34.2)	40.9 (40.4, 41.4)	48.3 (47.8, 48.8)	56.0 (55.2, 56.9)	61.0 (59.9, 62.1)	41.7 (41.3, 42.0)
2009	28.0 (27.5, 28.6)	33.7 (33.2, 34.1)	41.0 (40.4, 41.4)	49.2 (48.6, 49.9)	57.8 (57.0, 58.4)	62.5 (61.7, 63.5)	41.9 (41.6, 42.3)
2011	34.3 (33.7, 35.1)	42.3 (41.5, 42.9)	50.5 (50.0, 51.1)	58.4 (57.9, 58.9)	65.1 (64.6, 65.7)	68.4 (67.7, 69.2)	50.1 (49.8, 50.5)
Women							
1991	26.5 (26.2, 27.0)	30.8 (30.5, 31.1)	35.6 (35.2, 35.8)	40.6 (40.2, 40.9)	45.3 (44.9, 45.6)	48.1 (47.6, 48.8)	35.8 (35.5, 36.1)
1993	26.5 (26.1, 26.8)	31.1 (30.6, 31.5)	36.6 (36.2, 36.9)	42.5 (42.1, 42.7)	47.5 (47.0, 48.0)	50.1 (49.6, 50.8)	36.9 (36.6, 37.2)
1997	26.5 (26.1, 27.0)	30.6 (30.2, 31.0)	35.6 (35.3, 35.8)	41.0 (40.7, 41.5)	46.3 (45.8, 46.9)	49.8 (49.1, 50.5)	36.1 (35.8, 36.4)
2000	25.6 (25.1, 26.0)	29.8 (29.4, 30.0)	34.7 (34.5, 35.0)	40.0 (39.7, 40.3)	45.4 (44.9, 45.9)	49.1 (48.3, 50.1)	35.2 (34.9, 35.5)
2004	25.4 (24.8, 25.7)	29.9 (29.5, 30.2)	35.4 (35.1, 35.7)	41.8 (41.4, 42.4)	49.3 (48.5, 49.9)	54.0 (53.1, 54.7)	36.3 (36.0, 36.6)
2006	26.0 (25.6, 26.3)	30.6 (30.2, 31.0)	36.4 (36.0, 36.8)	43.8 (43.3, 44.2)	51.2 (50.4, 52.0)	55.6 (54.9, 56.4)	37.6 (37.3, 37.9)
2009	25.9 (25.3, 26.2)	30.5 (30.1, 30.8)	36.7 (36.3, 37.0)	44.6 (44.1, 45.2)	52.7 (52.2, 53.5)	57.3 (56.7, 58.4)	38.0 (37.7, 38.3)
2011	31.2 (30.4, 31.8)	39.0 (38.3, 39.7)	47.2 (46.7, 47.8)	54.4 (54.0, 54.8)	60.0 (59.6, 60.4)	62.9 (62.4, 63.6)	46.5 (46.2, 46.8)

(a)



(b)

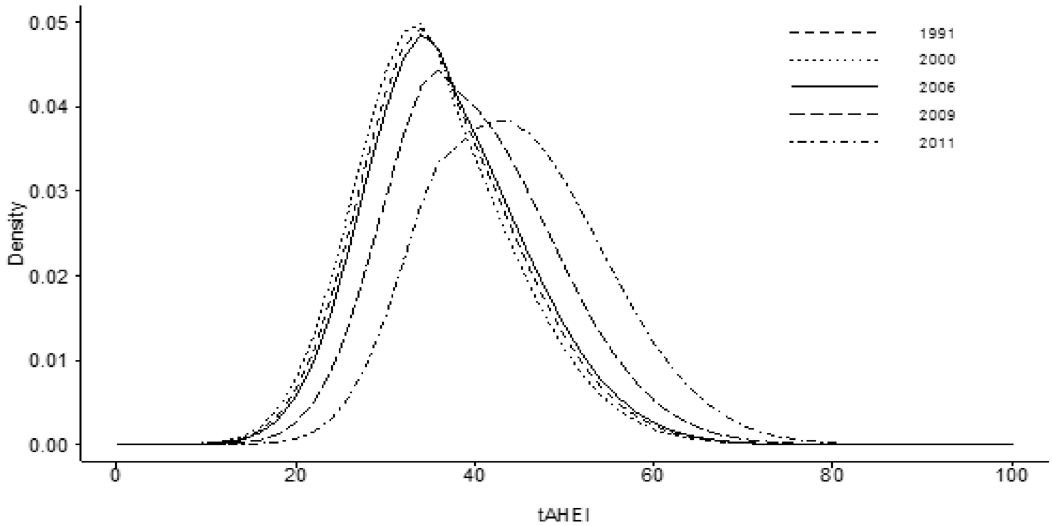
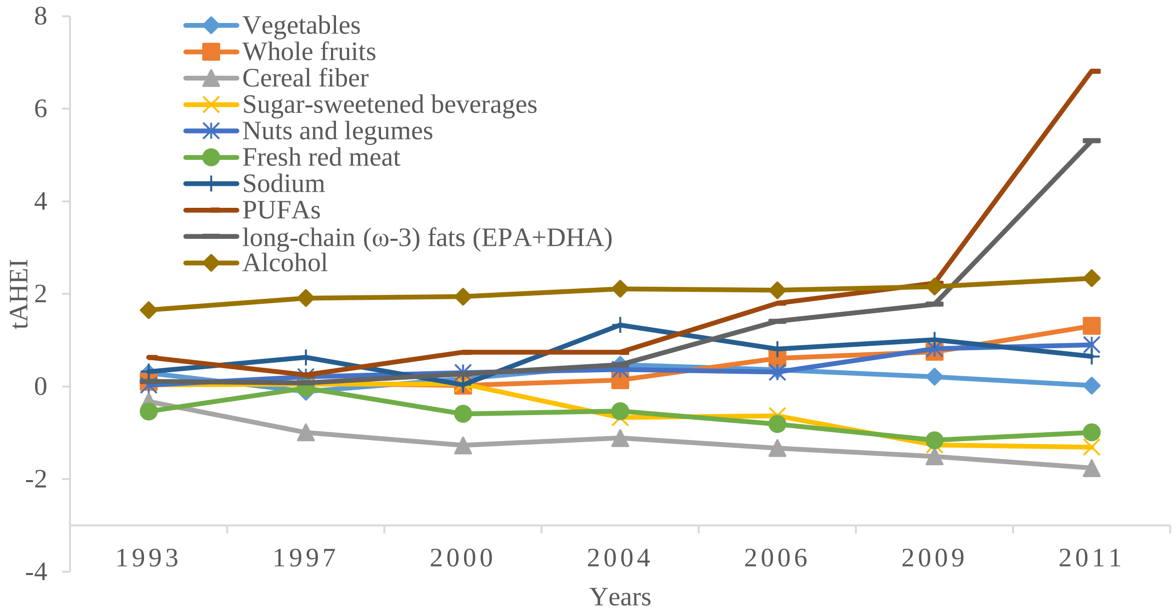


Figure 4.1. Shifts in distribution of the crude tAHEI scores among men (a) and women (b), CHNS, 1991–2011

(a)



(b)

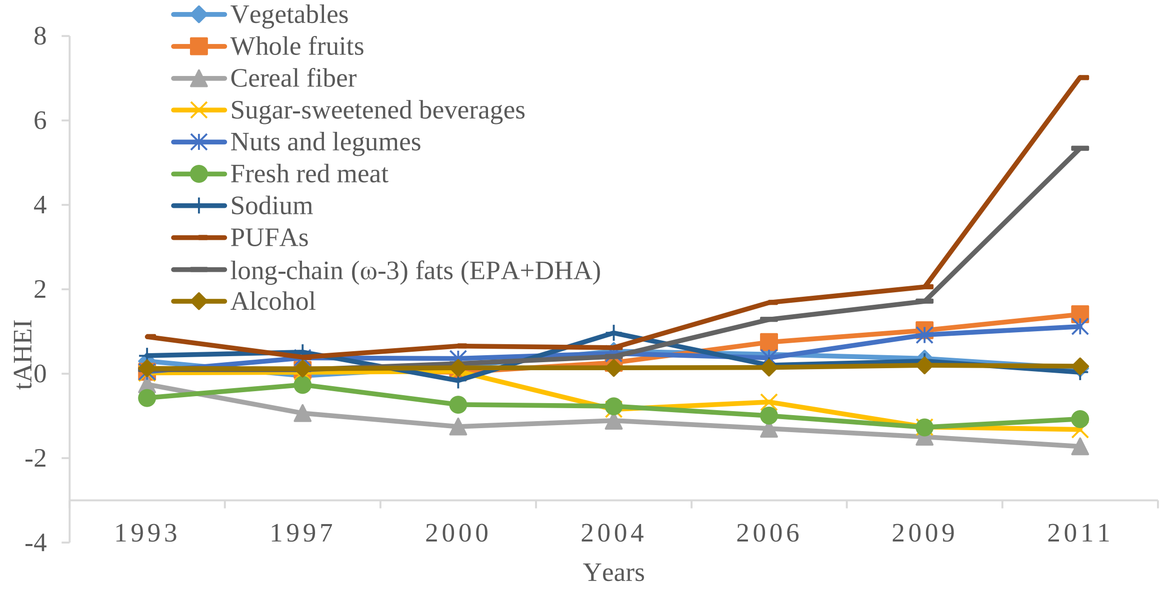
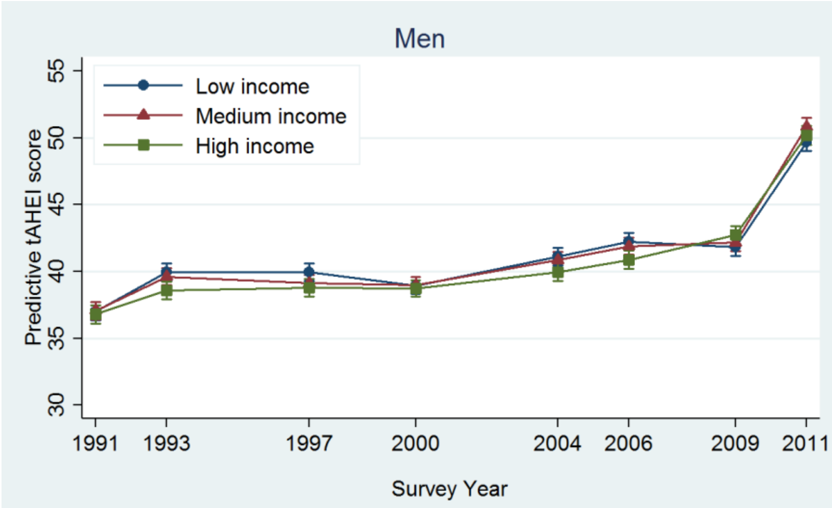
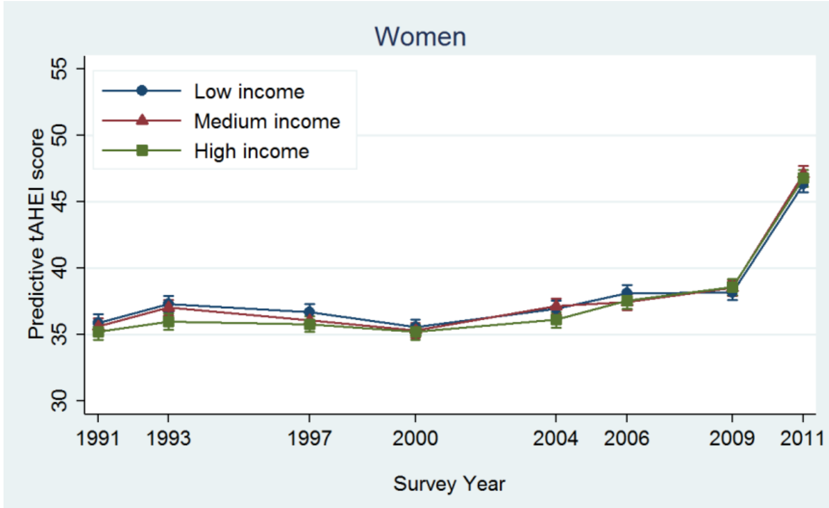
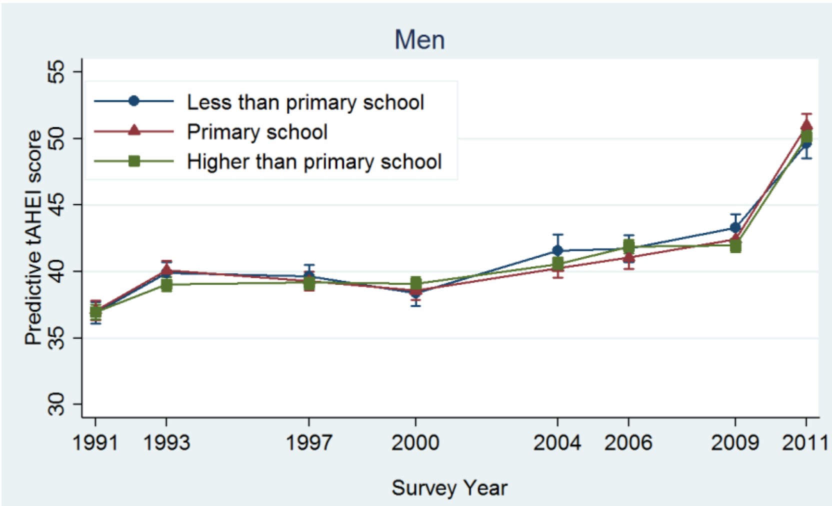
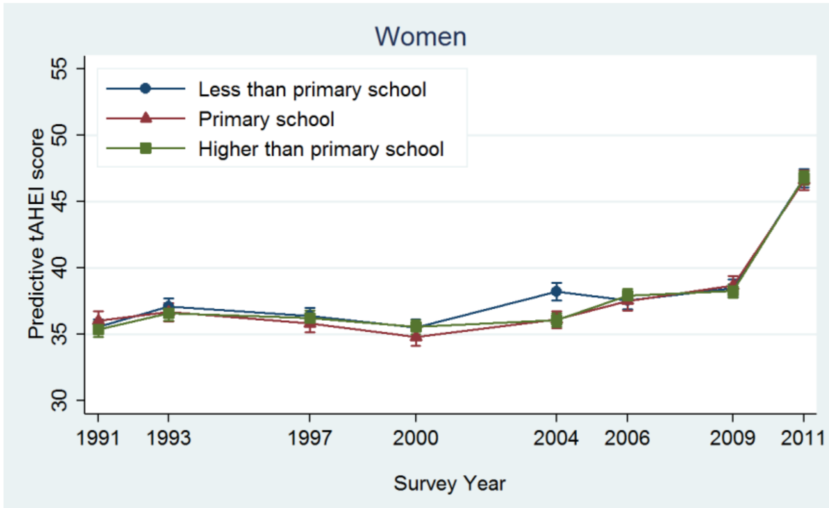


Figure 4.2. Estimated shifts in covariate-adjusted tAHEI component score among men (a) and women (b), CHNS, 1991–2011


Men
Low income
Medium income
High income
Predictive tAHEI score
30
35
40
45
50
55
1991
1993
1997
2000
2004
2006
2009
2011
Survey Year


Women
Low income
Medium income
High income
Predictive tAHEI score
30
35
40
45
50
55
1991
1993
1997
2000
2004
2006
2009
2011
Survey Year


Men
Less than primary school
Primary school
Higher than primary school
Predictive tAHEI score
30
35
40
45
50
55
1991
1993
1997
2000
2004
2006
2009
2011
Survey Year


Women
Less than primary school
Primary school
Higher than primary school
Predictive tAHEI score
30
35
40
45
50
55
1991
1993
1997
2000
2004
2006
2009
2011
Survey Year

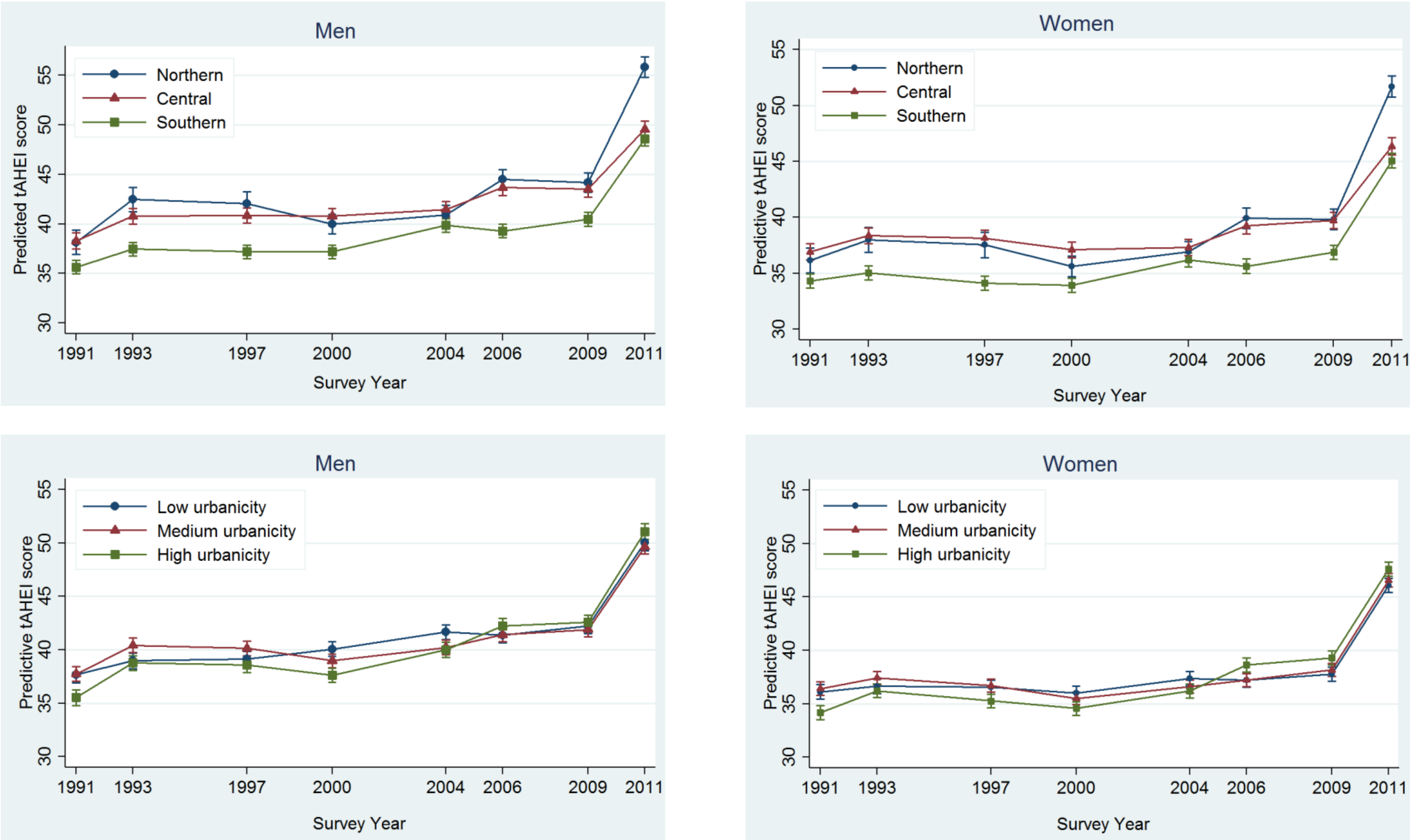


Figure 4.3. Predicted tAHEI score across demographic and socioeconomic factors among adults, CHNS, 1991–2011

CHAPTER 5: THE IMPACT OF FIFTEEN-YEAR TRENDS IN DIET QUALITY ON DIABETES PREVALENCE AMONG ADULTS IN CHINA

Overviews

Little is known about the relationship between overall diet quality over long periods and its impact on diabetes-related markers. The present study examined the impact of fifteen-year trends on diet quality on various biomarkers of diabetes among adults in China. The current analysis uses longitudinal diet data from 1991 to 2006 and fasting blood samples in 2009 for 4,734 adults aged 18 to 65 years from the China Health and Nutrition Survey. Dietary intake assessment was carried out over a 3-day period with 24-hour recalls and a household food inventory. The tailored Alternative Healthy Eating Index (tAHEI) was adapted from Harvard AHEI-2010 to measure overall diet quality. Annual change in the tAHEI score was calculated by the difference between the score of the last survey before 2009 and baseline score divided by years of follow-up. We categorized baseline tAHEI score into tertiles and divided annual change in score into five levels. Then we used mix-effect random intercept linear and logistic models to assess diabetes-related biomarkers (fasting glucose, HbA1c, insulin, HOMA-IR and diabetes) across levels of baseline tAHEI score and levels of annual changes in tAHEI score. Results showed that the adults with high baseline tAHEI scores had an average tAHEI score of 45.3 $\pm$4.9 points, 17.3 points and 9.2 points higher than the adults with low and medium baseline scores, who tended to be older and attain less years of education, and have higher proportion of being male, low income, high physical activity and living in central region and low urbanized communities. After adjustment for all socio-demographic and lifestyle factors, high baseline score had significantly lower insulin [-0.051 (-0.100,-0.002)] and lower HOMA-IR [-0.057 (-0.113,-0.001)] as compared to low baseline score; Large increase in score had significantly lower insulin [-0.086(-0.155,-0.017)] and lower HOMA-IR [-0.098(-0.177,-0.018)] as compared to maintenance of the score with additional adjustment for baseline score levels. No associations were observed with fasting glucose, HbA1c and the prevalence of diabetes. In conclusion, baseline and changes in diet quality were independently associated with lower HOMA-IR and lower insulin but not related to fasting glucose and HbA1c in adults. . Our findings suggest both early intervention and great improvement in diet quality may play the key role of in improving insulin resistance. Studies on overall diet quality in relation to longitudinal diabetes biomarkers and incident diabetes are needed.

Introduction

The prevention and treatment of diabetes has become a public health priority in China with several nationally representative surveys reporting the prevalence of diabetes in adults increasing from 0.67% in 1984, to 2.5% in 1994, and 9.7% in 2010 among adults in China[89-91]. The World Health Organization emphasizes the essential role of diet, together with alcohol consumption, smoking, and physical activity (PA), in diabetes epidemic[92]. Over the past two decades, China has experienced marked changes in diet [10, 11] and PA [12, 37] along with its rapid economic growth and social changes and the concurrent shifts in disease patterns [11]. Chinese food intake 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. Considering the multidimensional shifts in Chinese diet, the key issue is how to relate the 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[20]. The Harvard Healthy Eating Pyramid (HEP) is an example of evidence-based healthy diet guidance[24, 51, 93]. The alternative Healthy Eating Index 2010 (AHEI-2010) was created based on the recommendations of Harvard HEP[27]. One previous study indicated a 33% lower risk of diabetes related to higher AHEI-2010 scores in the Nurses' Health and Health Professionals Follow-up cohorts[27, 32]. Jacobs' study in the Hawaiian component of the multiethnic cohort suggested that higher AHEI-2010 score 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 years[69]. Recently a study found no association of baseline diet quality in 2006, measure by the adapted version of the Harvard AHEI-2010 for the Chinese diet, with diabetes prevalence in 2009 in Chinese adults[74]. However, how long-term changes in Chinese diet quality are related to diabetes risk remains unclear.

This study uses repeated dietary data for 4,734 adults between 1991 and 2006 to examine the association between baseline and changes in diet quality, measured by the tailored AHEI (named as tAHEI), and diabetes-related markers obtained in 2009, including HbA1c, glucose, insulin and homeostasis model of insulin resistance (HOMA-IR).

Subjects and Methods

The China Health and Nutrition Survey

Initiated in 1989, the China Health and Nutrition Survey (CHNS) 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 [20, 53]. 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 individuals in each household were surveyed for all data in each wave. Survey procedures have been described in detail elsewhere[21, 53]. The CHNS completed seven 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, Chinese Center for Disease Control and Prevention. All subjects provided written informed consent for their participation in the protocols.

Study Population

The present analysis selected adults aged 18 years at study entry to 65 years in 2009 who had at least two waves of dietary data from 1991 to 2006 and complete diabetes-related biomarkers at the 2009 examination. After excluding women currently pregnant or lactating during a survey year, those having implausible energy intakes (< 800 kilocalories [kcal] per day or > 6,000 kcal for men and < 600 kcal or > 4,000 kcal for women) [75], implausible biomarker values, missing baseline socio-demographic variables and baseline diagnosed diabetes, our final sample included 4,734 participants (2,263 men; 2,471 women).

Assessment of Diet Quality

Dietary intake was assessed by collecting three consecutive 24-hour dietary recalls 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[54, 76].

We used the tAHEI, tailored from the Harvard AHEI-2010[27], to assess diet quality. The tailoring methods are described in detail elsewhere [74]. In general, major tailoring includes: (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 juices intake from the past year FFQ in available survey years to reduce the potential underestimation of 24 h recall due to episodically 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 (about 3.1% of total meat) and few adults consumed processed meat higher than 64g [13]; (5) linking all Chinese foods to the US Food and Drug Administration (USDA) Food and Nutrient Database for Dietary Studies (FNDDS) [56] and National Nutrient Database for Standard Reference [57] to estimate polyunsaturated fatty acid (PUFA) and long chain (ω-3) fatty acid intake; (6) omitting the *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). **Table 5.1** illustrates the components and scaling methods of the tAHEI. We used the three-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.

Assessment of baseline tAHEI score and changes in tAHEI score

The CHNS is an open cohort study and participants have different entry time. 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 the tAHEI scores were calculated as the difference between the score of the last survey before 2009 and the baseline score divided by years of follow-up. Then we classified the participants into five categories, large decrease (decrease in tAHEI score per year was more than 1.5 points), small decrease (decrease in score was between 0.5 points and 1.5 points), maintenance (change in score was between -0.5 points and 0.5 points), small increase (increase in score was between 0.5 points and 2.0 points), and large increase (increase in score was more than 2.0 points). There were 10.1%, 17.0%, 37.4%, 25.6% and 10.0% of adults in the categories of large decrease, small decrease, maintenance, small increase and large increase, respectively.

Assessment of Diabetes-related Markers

In the 2009 CHNS, overnight fasting blood samples were collected with venipuncture by trained experienced physicians, phlebotomist or nurses. Plasma and serum samples were then frozen, and stored at -86 ℃ for later laboratory analysis. All samples were analyzed with strict quality control.

Whole blood was immediately centrifuged and serum was tested for glucose using a glucose oxidase phenol 4-aminoantipyrine peroxidase kit (Randox, Crumlin, UK) and a Hitachi 7600 analyzer (Hitachi; Tokyo, Japan). Serum insulin was tested using a radioimmunology assay kit (North Institute of Biological Technology; Beijing, China) using a XH-6020 gamma counter (North Institute of Biological Technology). Whole blood HbA1c was measured by high performance liquid chromatography with an automated glycohemoglobin analyzer (model HLC-723 G7; Tosoh Corporation, Tokyo, Japan). The homeostasis model of insulin resistance (HOMA-IR) was estimated as [((fasting insulin (μU/ml)* fasting glucose (mmol/l))/ 22.5]. Diabetes were defined based on HbA1c ≥6.5% and based on fasting glucose ≥7.0*mmol/l.*

Fasting glucose, HbA1c, insulin and HOMA-IR were natural logarithm-transformed to fit a relatively normal distribution.

Covariates

Trained interviewers used standard questionnaires to collect baseline information on annual family income, individual education level, physical activity, 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[65].

Physical activity (PA) includes four domains: occupational, household chore, leisure time, and transportation activities. All activities were reported in average hours per week during the past year[37]. We converted time spent in each activity into metabolic equivalent of task (MET) hours per week based on the Compendium of Physical Activities[68]. The MET hours per week measurement accounts for both the average intensity of each activity and the time spent in each activity.

We also considered age in 2006, sex, 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 across levels of annual changes in scores, respectively. Then we compared socio-demographic factors, lifestyle factors, and diabetes-related biomarkers across levels of baseline scores. We tested *P*-trend by assigning median values to tertiles of baseline tAHEI scores and levels of annual changes in tAHEI score, respectively, and this variable was entered as a continuous term in the mixed-effect linear regression models for each component score, continuous demographic factors, and continuous diabetes-related biomarkers, while chi-square tests were used for categorical variables.

Next, we tested but found no statistically significant interactions ($p<0.050$ between levels of annual changes in tAHEI scores with levels of baseline tAHEI scores. Then, we performed a series of mixed-effect linear models for continuous diabetes-related markers and mixed-effect logistic models for diabetes prevalence with baseline tAHEI score and annual changes in tAHEI scores as indicator variables, respectively, adjustment for gender, age in

2006, baseline income, education, urbanicity index, geographical region, physical activity, smoking status, total energy intake, and baseline tAHEI score tertiles (only for changes in tAHEI scores as indicator variable). We considered low baseline scores or maintenance of scores as the reference categories, respectively. Random intercepts were included to account for community-level clustering.

Due to natural logarithmic-transformed markers as the outcome predictors, the regression coefficients were multiplied by 100 and interpreted as the percent change in each marker for being in a given class compared to the reference class.

We fitted mixed-effect linear and logistic models using STATA 14.1 (StataCorp., TX). For all other descriptive analyses, we used SAS 9.4 (SAS Institute, NC). All statistical tests were two-tailed and considered significant at $p < 0.05$.

Results

Component scores profiles of levels of baseline tAHEI scores and average annual change in each component score across levels of annual changes in tAHEI scores

As shown in **Table 5.2**, the adults with high baseline tAHEI scores had an average score of 45.3 ± 4.9 points, 17.3 points and 9.2 points higher than the adults with low and medium baseline scores, respectively. In addition, the scores of nuts and legumes, cereal fiber, and sodium contributed more to the disparity of levels of baseline scores (Table 5.2).

For annual changes in tAHEI scores, the adults in the large decrease group had big decline in the scores of nuts and legumes, fresh red meat and sodium (all *P*-for-trend<0.0001), whereas those in the large increase group had large increase in the scores of nuts and legumes, PUFA, and EPA plus DHA (all *P*-for-trend<0.0001).

Demographic and lifestyle characteristics across baseline tAHEI score

In comparison with adults in low baseline tAHEI score, adults in high baseline score were older and attained less years of education, and had higher proportion of being male, low income, high physical activity and living in central region and low urbanized communities **(Table 5.3)**.

Diabetes and insulin markers in 2009 across baseline tAHEI score

The adults in high baseline tAHEI score tended to have higher HbA1c (p-trend <0.0001), but lower insulin (p-trend <0.001) and HOMA-IR (p-trend< 0.05), while fasting glucose were not significantly different across baseline score tertiles (p-trend=0.19) (Table 5.4).

Diabetes prevalence defined by fasting glucose and HbA1c were not significantly different across baseline score tertiles **(Table 5.4)**.

Association between baseline tAHEI score and diabetes-related biomarkers

After adjustment for all potential covariates, high baseline tAHEI scores were significantly associated with lower insulin [-0.051; 95%CI: -0.100,-0.002] and lower HOMA-IR [-0.057; 95%CI: -0.113,-0.001) as compared to low baseline scores, respectively, while no associations were observed with fasting glucose and HbA1c **(Table 5.5)**.

Association between annual changes in tAHEI scores and diabetes-related biomarkers

Table 5.6 showed that large increase in scores had significantly lower insulin [-0.071; 95%CI: -0.139,-0.002] and lower HOMA-IR [-0.081; 95%CI: -0.159,-0.003] as compared to maintenance of the scores, respectively, adjustment for all socio-demographic and lifestyle factors. Additional adjustment for baseline score enhanced the magnitude of association slightly. There were no associations between annual changes in scores and fasting glucose and HbA1c.

Association between baseline and annual changes in tAHEI scores and diabetes prevalence, respectively

As shown in **Table 5.7**, large decrease and small increase in tAHEI scores were associated with lower prevalence of diabetes (defined by fasting glucose) as compared with maintenance score, respectively, after adjustment for socio-demographic, lifestyle factors and baseline score (p-trend=0.86), while baseline tAHEI score was not associated with the prevalence of diabetes defined by both HbA1c and fasting glucose.

Discussion

Earlier research found that the tAHEI score in 2006 was a predictor of 3-year risk of high low density lipoprotein cholesterol but not diabetes risk in Chinese adults [74]. One concern is that long-term changes in diet quality may be related to diabetes risk. In this study, we investigated the association between baseline diet quality and annual changes in diet quality during the follow-up period from 1991 to 2006 and diabetes markers in 2009 in Chinese adults ages 18 to 65. We found that the adults with low socioeconomic status and in low urbanized communities tended to have relatively high baseline diet quality (45.3 points of 100 points) and about 10% of adults had big annual decrease in diet quality, 10% of adults big annual improvement diet quality, the majority of adults remained their diet quality or just shifted a little bit during the follow-up period. Our study also found that high baseline diet quality was associated with about 5.1% and 5.7% lower insulin and HOMA-IR as compared to low baseline diet quality, while large increase in diet quality was, independently from baseline diet quality, associated with about 8.6% and 9.8% lower insulin and HOMA-IR as compared to maintenance of diet quality in adults. However, we found no association between baseline and changes in diet quality and fasting glucose and HbA1c. The findings suggested baseline and annual changes in diet quality may have potential threshold effect on insulin and HOMA-IR. Longitudinal research on the relation of diet quality and diabetes markers are needed to confirm our results.

Our study found 39.5% and 30.9% lower prevalence of diabetes comparing the categories of small increase and large decrease versus maintenance of the scores, respectively, while baseline diet quality was not related to diabetes prevalence. Our results were inconsistent with several suggesting negatively predictive capacity of the AHEI-2010 in diabetes risk, such as 33% lower risk of diabetes in the Nurses' Health and Health Professionals 24-year Follow-up cohorts [27, 32] and a 13-28% lower risk of type 2 diabetes in white but not in Japanese-American and Native Hawaiian participants aged 45-75 years [69]. There are several possible reasons to explain inconsistent results. First, the AHEI-2010 was not based on Asian population evidence of diet-disease relationship and the evidence-based threshold effect of diabetes-related components of the AHEI-2010 in the Western population may not be the case for Chinese population. Second, the adaption version tAHEI was not identical to the original Harvard AHEI-2010 due to several methodological tailoring ways for Chinese diet and incomplete China FCT[27, 74] . Third, components profiles of baseline score tertiles need to be considered, especially for those components which have been suggested to be associated with diabetes risk, including vegetables and fruits, SSBs, fresh red meat, and cereal fibers. The high baseline score category had 4.6 points, 3.5 points, and 3.0 points higher of nuts and legumes, fresh red meat, and cereal fiber than the low baseline score category, but slight difference in vegetables and 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 higher risk of diabetes[94]. In addition, one recent study suggested that the effect of some diabetes-associated components may be diluted in an index consisting other components[95].

Our study has important strengths, including relatively precise estimate of dietary intakes from the combination of multiple dietary assessment methods which remain consistent during the period of the CHNS, the long follow-up period, approximate 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 exactly time of diabetes onset. However, we deleted baseline doctor-diagnosed diabetic adults and evaluated annual changes in diet quality with maximum 15-year follow-up from 1991 to 2006 in relation to the diabetes markers in 2009, which may reduce the possibility of dietary intakes changes due to diabetes onsets between 2006 and 2009. Second, we evaluated annual changes in diet quality using two time points of baseline and the last survey before 2009 and ignoring the potential fluctuate and uneven changes between the two time points. The entry year of the participants varied due to the open cohort nature of the CHNS. Finally, we calculated the tAHEI scores based on self-reported three consecutive 24-hour dietary recalls, which may have relatively limited correction 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, insulin but not related to fasting glucose andHbA1c in Chinese adults. Annual changes in diet quality was also negatively associated with risk of diabetes defined by fasting glucose. Our findings suggest both early intervention of diet quality and its great increase may play the key role of in improving insulin resistance. Studies on prospective associations between overall diet quality and longitudinal diabetes markers and incident diabetes are needed.

Tables and Figures

Table 5.1. Tailoring method of the Harvard AHEI-2010

Components	Criteria for minimum score(0) 1	Criteria for maximum score(10) 1	Comments on tailoring
Vegetables, g/d 2	0	≥591	5 servings/d (1 serving is 0.5 cup of vegetables)
Whole fruit, g/d 2	0	≥473	4 servings/d (1 serving is 0.5 cup of berries)
Cereal fiber, g/d 2	0	15	15 g cereal fiber as ideal on the basis of epidemiologic studies and the distribution in our cohorts.
Nuts and legumes, g/d 2	0	28	1 serving/d was considered to be ideal on the basis of the AHEI recommendations and the current literature. One serving is 1 oz of nuts or 1 tablespoon (15 ml) of peanut butter. *
Long-chain (n-3) fats (EPA+DHA), mg/d 3	0	250	The cutoff for optimal intake (250 mg/d) is about 100g/d of fish
PUFA, % of energy 3	≤2	≥10	The highest score was given to individuals with 10% of total energy intake from PUFA. PUFA does not include EPA or DHA intake *
Red/processed meat, g/d 2	≥170 (red meat)	0	An upper limit of 1.5 servings/d (1 serving is 4 oz of unprocessed meat or 1.5 oz of processed meat) *
Sodium, mg/d	Highest decile	Lowest decile	The cutoffs for sodium were based on deciles of distribution in the study population. This method is used by the AHEI-2010 due to lack of brand specificity in the FFQ to accurately estimate absolute intake.
SSB and fruit juice, g/d 2	≥227	0	≥1 serving/d was considered to be the least optimal. 1 serving is 8 oz. We use the past year FFQ of SSB and fruit juice, instead of 3 consecutive 24 hour recall, to get more precise estimate of daily intake for episodically consumed SSB and fruit juice.
Alcohol, drinks/d 4			
Women	≥2.5	0.5-1.5 (0-<0.5, score = 2.5)	One drink is 4 oz of wine, 12 oz of beer, or 1.5 oz of liquor. For both men and women with alcohol intake less than 0.5 including zero, we score this component 2.5 points.
Men	≥3.5	0.5-2.0 (0-<0.5, score = 2.5)	

Table 5.1. Tailoring method of the Harvard AHEI-2010 (continued)

Components	Criteria for minimum score(0) 1	Criteria for maximum score(10) 1	Comments on tailoring
Trans fat, % of energy	---	---	We omitted trans fat component in the tailored AHEI-2010 given a lack of information on trans fat composition of all eaten food in both China and USDA FCT.
Total score	0	100	

Abbreviations: AHEI=Alternative Healthy Eating Index; CHNS= China Health and Nutrition Survey; DHA= Docosahexenoic acid; EPA= Eicosapntemacnioc Acid; FNDDS=Food and Nutrient Database for Dietary Studies; HEP=Healthy Eating Pyramid; PUFA=polyunsaturated fatty acid; SR=standard references; SSB=sugar-sweetened beverages. 1 Intermediate intakes were scored between the minimum and the maximum according to the formula: component score= (Maximum score / (Amax-Amin))*(X-Amin) for adequacy components; component score = Maximum score - maximum score / (Amax-Amin))*(X-Amin) for moderate components (red/processed meat, sodium, SSB and fruit juice, and alcohol); Amax is maximum amount of the component corresponding to the recommended intake, while Amin is minimum amount of the component corresponding to the recommended intake. X: amount consumed by the individual. 2 Serving units were transferred to grams to match the CHNS diet data. (1 cup = 236.59 g; 1 oz = 28.35 g); 3 We additionally linked all Chinese FCT foods to the USDA FNDDS and SR nutrient databases to estimate fatty acid composition which is unavailable from the China FCT. 4 Grams units were transferred to drinks for alcohol component.

Table 5.2. Components scores of the study population by levels of baseline tAHEI scores and levels of annual changes in tAHEI score, CHNS

	Baseline tAHEI score				Annual changes in tAHEI score					
	Low	Medium	High	*P*-trend	Large decrease	Small decrease	Maintenance	Small increase	Large increase	*P*-trend
Vegetables	5.0 ± 2.4	5.5 ± 2.6	6.3 ± 2.7	<0.001	-0.2 ± 1.1	0 ± 0.4	0 ± 0.4	0.1 ± 0.5	0.4 ± 1.1	<0.001
Whole fruits	0.3 ± 0.9	0.3 ± 1.2	0.5 ± 1.7	<0.001	-0.1 ± 0.8	0 ± 0.3	0 ± 0.2	0.1 ± 0.5	0.4 ± 1.1	<0.001
Cereal fiber	3.3 ± 1.9	5.1 ± 2.9	6.3 ± 3.0	<0.001	-0.3 ± 0.9	-0.2 ± 0.3	-0.1 ± 0.2	0 ± 0.3	0.1 ± 0.9	<0.001
SSBs and fruit juices	9.6 ± 1.7	9.9 ± 0.8	9.9 ± 0.7	<0.001	-0.2 ± 1.0	-0.1 ± 0.4	0 ± 0.3	0 ± 0.4	0.2 ± 1.1	<0.001
Nuts and legumes	1.9 ± 3.2	3.8 ± 4.2	6.5 ± 4.3	<0.001	-1.0 ± 1.7	-0.3 ± 0.7	0 ± 0.6	0.3 ± 0.8	0.9 ± 2.1	<0.001
Fresh red meat	4.7 ± 3.5	7.4 ± 3.0	8.2 ± 2.6	<0.001	-0.5 ± 1.3	-0.1 ± 0.6	-0.1 ± 0.4	0.1 ± 0.6	0.4 ± 1.5	<0.001
Sodium	0.5 ± 1.6	1.1 ± 2.5	3.0 ± 4.1	<0.001	-0.5 ± 1.6	-0.1 ± 0.6	0 ± 0.4	0.1 ± 0.7	0.4 ± 1.5	<0.001
PUFA	0 ± 0	0 ± 0.7	0.5 ± 2.3	<0.001	-0.3 ± 1.2	0 ± 0.3	0 ± 0.3	0.2 ± 0.4	0.8 ± 1.6	<0.001
EPA+DHA	0 ± 0	0 ± 0	0.4 ± 1.8	<0.001	-0.2 ± 1.0	0 ± 0.3	0 ± 0.2	0.1 ± 0.4	0.7 ± 1.5	<0.001
Alcohol drinking	2.7 ± 1.2	2.9 ± 1.6	3.7 ± 2.7	<0.001	-0.3 ± 1.1	0 ± 0.4	0 ± 0.3	0.1 ± 0.5	0.4 ± 1.2	<0.001
Total score	28.0 ± 3.7	36.1 ± 1.9	45.3 ± 4.9		-3.6 ± 2.6	-0.9 ± 0.3	0 ± 0.3	1.1 ± 0.4	4.7 ± 3.3	

Abbreviations: AHEI = Alternative Healthy Eating Index; CHNS = China Health and Nutrition Survey; DHA = docosahexenoic acid; EPA = eicosapntemacnioc acid; PUFA = polyunsaturated fatty acid; SSB = sugar-sweetened beverage; tAHEI=tailored Alternative Healthy Eating Index. Data shown as mean ± standard deviance; General linear models was used to test *P*-trend by assigning median values to tertiles of baseline tAHEI scores and levels of annual changes in tAHEI score, respectively, and this variable was entered as a continuous term in the regression models.

Table 5.3. Demographic characteristics of the study population by levels of baseline tAHEI scores, CHNS

	Baseline tAHEI score tertiles		
	Low	Medium	High
N (%)	1578(33.3)	1578(33.3)	1578(33.3)
Median Score (Q1, Q3)	28.7(25.6, 30.9)	31.0(34.5, 37.6)	44.2(41.7,47.6)
Age in 2006 (years)[1,**]	46.1 ±9.3[a]	46.7 ±9.2[a,b]	47.1 ±9.0 [b]
Male (%)[**]	41.0	46.6	55.8
Income (%) [**]			
Low	27.0	35.6	37.4
Medium	33.1	32.5	34.4
High	39.9	31.9	28.2
Education (years) [1,***]	7.7 ±3.7 [a]	7.0 ±3.7 [b]	6.8 ±3.6 [b]
Urbanicity (%)[**]			
Low	23.1	37.1	39.9
Medium	31.6	32.5	35.9
High	45.4	30.4	24.1
Region (%) [**]			
North	17.8	22.3	25.0
Central	26.7	35.0	40.2
South	55.5	42.6	34.7
Physical activity (%)[**]			
Low	42.6	29.6	27.8
Medium	30.9	33.6	35.6
High	26.5	36.8	36.7
Current smoker (%)			
Male	56.1	61.0	60.2
Female	2.3	4.2	3.6

Abbreviations: CHNS=China Health and Nutrition Survey; tAHEI=tailored Alternative Healthy Eating Index. [1] Data shown as mean ± standard deviance; [2] General linear models was used to test p-for-trend for continuous variables and chi-square test for categorical variables across baseline tAHEI score tertiles. $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.

Table 5.4. Diabetes and insulin markers in 2009 by levels of baseline tAHEI scores, CHNS

	baseline tAHEI score			*P*-value
	Low	Medium	High	
Glucose (mmol)	5.17(4.75,5.65)	5.09(4.72,5.62)	5.12(4.7, 5.63)	0.16
Log glucose (mmol)	4.56±0.20	4.55±0.19	4.55±0.21	0.19
HbA1c (%)	5.40(5.20,5.80)	5.50(5.20,5.80)	5.60(5.30,5.90)	<0.001
Log HbA1c (%)	1.71±0.12	1.72±0.14	1.73±0.14	<0.001
Insulin (uIU/ml)	10.71(7.51,15.37)	9.92(7.09,14.31)	9.89(6.93,14.36)	<0.01
Log insulin (uIU/ml)	2.40±0.66	2.33±0.67	2.33±0.67	<0.01
HOMA-IR	2.46(1.68,3.72)	2.24(1.56,3.44)	2.23(1.52,3.43)	<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 glucose (%)	6.34	6.08	6.91	0.62

Abbreviations: CHNS=China Health and Nutrition Survey; HbA1c= Hemoglobin A1c; HOMA-IR=Homeostasis model of insulin resistance; tAHEI=tailored Alternative Healthy Eating Index. Data shown as median (Q1, Q3) for diabetes markers or mean ± standard error for logarithmically transformed markers. Statistical significance for marker heterogeneity using non-parametric median test, for diabetes prevalence using chi-square test, and for logarithmically transformed markers using general linear models to test p-trend across baseline tAHEI score tertiles.

Table 5.5. Association between levels of baseline tAHEI scores and fasting glucose, HbA1c, insulin and Log HOMA-IR in 2009 in Chinese adults [a]

	Model 1[b]	Model 2	Model 3	Model 4	Model 5
Log glucose					
Low	Ref	Ref	Ref	Ref	Ref
Medium	-0.006(-0.020,0.008)	-0.009(-0.023,0.005)	-0.009(-0.023,0.005)	-0.008(-0.022,0.006)	-0.008(-0.022,0.006)
High	-0.001(-0.016,0.014)	-0.008(-0.023,0.007)	-0.008(-0.023,0.007)	-0.007(-0.023,0.008)	-0.007(-0.023,0.008)
P-trend [c]	0.918	0.345	0.336	0.353	0.361
Log HbA1c					
Low	Ref	Ref	Ref	Ref	Ref
Medium	0.004 (-0.005,0.013)	0.002(-0.006,0.011)	0.001(-0.008,0.010)	0.001(-0.008,0.010)	0.001(-0.008,0.010)
High	0.010(0.000,0.019)*	0.006(-0.003,0.015)	0.004(-0.006,0.013)	0.004(-0.006,0.013)	0.003(-0.006,0.013)
P-trend	0.044	0.207	0.424	0.416	0.472
Log insulin					
Low	Ref	Ref	Ref	Ref	Ref
Medium	-0.045(-0.091,0.000)	-0.042(-0.087,0.004)	-0.046(-0.092,-0.000)*	-0.043(-0.089,0.002)	-0.043(-0.089,0.002)
High	-0.053(-0.101,-0.005)*	-0.045(-0.094,0.003)	-0.052(-0.101,-0.003)*	-0.051(-0.100,-0.002)*	-0.051(-0.100,-0.002)*
P-trend	0.035	0.076	0.044	0.048	0.049
Log HOMA-IR					
Low	Ref	Ref	Ref	Ref	Ref
Medium	-0.051(-0.103,0.001)	-0.050(-0.103,0.002)	-0.055(-0.107,-0.002)*	-0.052(-0.104,0.001)	-0.052(-0.104,0.001)
High	-0.053(-0.108,0.002)	-0.052(-0.108,0.004)	-0.059(-0.115,-0.003)*	-0.057(-0.113,-0.001)*	-0.057(-0.113,-0.001)*
P-trend	0.069	0.078	0.046	0.051	0.052

Abbreviations: CI=confidence interval; HbA1c= Hemoglobin A1c; HOMA-IR=Homeostasis Model of Insulin Resistance. [a] Baseline tAHEI score are categorized into tertiles (low, medium, and high), low level was the reference group. [b] Model 1crude without any adjustment; Model 2 adjust for age in 2006, sex, baseline income (tertiles) and education; Model 3 additional adjust for geographic region and baseline urbanicity index (tertiles); Model 4 plus baseline physical activity (tertiles) and smoking status. Model 5 plus baseline energy intake. Fasting glucose, HbA1c, insulin and HOMA-IR were logarithmically transformed. [c] P-trend was calculated by assigning median values to tertiles of baseline tAHEI scores, and this variable was entered as a continuous term in the models.

Table 5.6. Association between levels of annual change in tAHEI scores and Log fasting glucose, HbA1c, insulin and HOMA-IR in 2009 in adults [a]

	Model 1[b]	Model 2	Model 3	Model 4	Model 5
Log glucose					
Large decrease	-0.026(-0.046,-0.006)*	-0.013(-0.033,0.008)	-0.015(-0.035,0.006)	-0.015(-0.036,0.005)	-0.014(-0.036,0.007)
Small decrease	-0.008(-0.025,0.009)	-0.005(-0.022,0.011)	-0.006(-0.023,0.011)	-0.006(-0.023,0.011)	-0.005(-0.022,0.012)
Maintenance	Ref	Ref	Ref	Ref	Ref
Small increase	-0.004(-0.019,0.010)	-0.002(-0.017,0.013)	-0.003(-0.017,0.012)	-0.003(-0.017,0.012)	-0.004(-0.019,0.011)
Large increase	-0.019(-0.040,0.001)	-0.006(-0.028,0.015)	-0.009(-0.030,0.012)	-0.010(-0.031,0.011)	-0.012(-0.034,0.010)
P-trend [c]	0.758	0.654	0.687	0.710	0.977
Log HbA1c					
Large decrease	-0.015(-0.027,-0.002)*	-0.003(-0.015,0.010)	-0.005(-0.017,0.008)	-0.005(-0.018,0.008)	-0.007(-0.020,0.007)
Small decrease	-0.002(-0.012,0.009)	0.000(-0.010,0.010)	-0.000(-0.010,0.010)	-0.000(-0.010,0.010)	-0.002(-0.012,0.009)
Maintenance	Ref	Ref	Ref	Ref	Ref
Small increase	-0.004(-0.013,0.005)	-0.001(-0.010,0.008)	-0.002(-0.011,0.007)	-0.002(-0.011,0.007)	-0.001(-0.011,0.008)
Large increase	-0.014(-0.027,-0.001)*	-0.001(-0.014,0.012)	-0.004(-0.017,0.009)	-0.004(-0.017,0.009)	-0.004(-0.017,0.010)
P-trend	0.719	0.967	0.893	0.891	0.843
Log insulin					
Large decrease	-0.001(-0.066,0.063)	-0.019(-0.085,0.047)	-0.024(-0.090,0.043)	-0.028(-0.094,0.039)	-0.010(-0.080,0.059)
Small decrease	-0.016(-0.069,0.038)	-0.019(-0.072,0.035)	-0.020(-0.073,0.033)	-0.021(-0.074,0.032)	-0.008(-0.063,0.047)
Maintenance	Ref	Ref	Ref	Ref	Ref
Small increase	0.013(-0.034,0.059)	0.012(-0.035,0.059)	0.011(-0.036,0.057)	0.010(-0.037,0.057)	-0.001(-0.048,0.047)
Large increase	-0.042(-0.107,0.024)	-0.061(-0.128,0.007)	-0.066(-0.134,0.002)	-0.071(-0.139,-0.002)*	-0.086(-0.155,-0.017)*
P-trend	0.571	0.509	0.489	0.478	0.082

Table 5.6. Association between levels of annual change in tAHEI scores and Log fasting glucose, HbA1c, insulin and HOMA-IR in 2009 in adults [a] (continued)

	Model 1[b]	Model 2	Model 3	Model 4	Model 5
Log HOMA-IR					
Large decrease	-0.028(-0.102,0.046)	-0.032(-0.107,0.044)	-0.038(-0.114,0.038)	-0.043(-0.119,0.033)	-0.025(-0.105,0.054)
Small decrease	-0.024(-0.085,0.037)	-0.025(-0.085,0.036)	-0.026(-0.087,0.035)	-0.028(-0.089,0.033)	-0.014(-0.077,0.049)
Maintenance	Ref	Ref	Ref	Ref	Ref
Small increase	0.009(-0.045,0.062)	0.010(-0.043,0.064)	0.008(-0.045,0.062)	0.007(-0.046,0.061)	-0.004(-0.059,0.051)
Large increase	-0.062(-0.137,0.013)	-0.067(-0.145,0.010)	-0.075(-0.153,0.003)	**-0.081(-0.159,-0.003)**[*]	**-0.098(-0.177,-0.018)**[*]
P-trend	0.655	0.657	0.631	0.615	0.135

Abbreviations: CI=confidence interval; HbA1c= Hemoglobin A1c; HOMA-IR=Homeostasis Model of Insulin Resistance. [a] Changes in tAHEI score per year are categorized into five levels, maintenance level was the reference group. [b] Model 1 Model 1crude without any adjustment; Model 2 adjust for age in 2006, sex, baseline income (tertiles) and education; Model 3 additional adjust for geographic region and baseline urbanicity index (tertiles); Model 4 plus baseline physical activity (tertiles) and smoking status. Model 5 plus baseline energy intake and levels of baseline score. Glucose, HbA1c, insulin and HOMA-IR were logarithmically transformed. [c] P-trend was calculated by assigning median values to each level of annual changes in tAHEI scores, and this variable was entered as a continuous term in the models.

Table 5.7. Association (OR and 95%CI) between baseline tAHEI scores or annual change of tAHEI scores and diabetes prevalence in 2009 in adults

	Model 1[a]	Model 2	Model 3	Model 4	Model 5
Diabetes defined by HbA1c					
Baseline tAHEI score [b]					
Low	Ref	Ref	Ref	Ref	Ref
Medium	0.983(0.728,1.328)	0.952(0.702,1.293)	0.900(0.666,1.216)	0.904(0.667,1.225)	0.888(0.653,1.209)
High	1.113(0.809,1.531)	1.040(0.747,1.447)	0.956(0.692,1.321)	0.957(0.690,1.328)	0.933(0.670,1.299)
P-trend [c]	0.495	0.792	0.832	0.839	0.730
Change in tAHEI score per year [d]					
Large decrease	0.628(0.377,1.047)	0.717(0.426,1.206)	0.657(0.391,1.103)	0.652(0.388,1.096)	0.631(0.364,1.095)
Small decrease	1.017(0.730,1.416)	1.046(0.747,1.464)	1.024(0.734,1.431)	1.025(0.734,1.431)	0.999(0.698,1.429)
Maintenance	Ref	Ref	Ref	Ref	Ref
Small increase	1.054(0.789,1.409)	1.104(0.819,1.487)	1.047(0.780,1.407)	1.047(0.780,1.407)	1.043(0.778,1.397)
Large increase	0.904(0.589,1.388)	1.027(0.650,1.625)	0.920(0.578,1.463)	0.910(0.572,1.450)	0.901(0.559,1.449)
P-trend	0.343	0.317	0.411	0.419	0.460
Diabetes defined by fasting glucose					
Baseline tAHEI score					
Low	Ref	Ref	Ref	Ref	Ref
Medium	0.958(0.733,1.250)	0.934(0.714,1.223)	0.934(0.712,1.225)	0.951(0.724,1.249)	0.950(0.723,1.249)
High	1.096(0.815,1.476)	1.028(0.761,1.388)	1.020(0.757,1.375)	1.029(0.763,1.388)	1.028(0.763,1.385)
P-trend	0.530	0.834	0.867	0.826	0.833

Table 5.7. Association (OR and 95%CI) between baseline tAHEI scores or annual change of tAHEI scores and diabetes prevalence in 2009 in adults (continued)

	Model 1[a]	Model 2	Model 3	Model 4	Model 5
Change in tAHEI score per year					
Large decrease	0.603(0.369,0.984)*	0.659(0.403,1.077)	0.633(0.387,1.034)	0.619(0.379,1.011)	0.605(0.368,0.994)*
Small decrease	0.937(0.686,1.279)	0.971(0.711,1.326)	0.954(0.696,1.307)	0.954(0.696,1.307)	0.942(0.676,1.313)
Maintenance	Ref	Ref	Ref	Ref	Ref
Small increase	0.710(0.531,0.949)*	0.707(0.528,0.948)*	0.694(0.519,0.929)*	0.693(0.518,0.926)*	0.691(0.516,0.925)*
Large increase	0.875(0.580,1.320)	0.926(0.605,1.418)	0.881(0.568,1.368)	0.849(0.545,1.322)	0.841(0.536,1.318)
P-trend	0.767	0.854	0.897	0.950	0.861

Abbreviations: CI=confidence interval; HbA1c= Hemoglobin A1c; OR=odds ratios; [a] Model 1 crude without any adjustment; Model 2 additional adjust for age in 2006 and sex, baseline income (tertiles) and education; Model 3 plus geographic region and baseline urbanicity index (tertiles); Model 4 plus baseline physical activity (tertiles) and smoking status. Model 5 plus baseline energy intake and baseline score tertiles (only for change in tAHEI score per year); Model 6 plus baseline BMI. [b] Baseline tAHEI score are categorized into tertiles (low, medium, and high), low level was the reference group. [c] P-trend was calculated by assigning median values to each level of baseline and annual changes in tAHEI scores, respectively, and entered as continuous terms in the models. [d] Changes in tAHEI score per year are categorized into five levels, maintenance level was the reference group.

CHAPTER 6: SYNTHESIS

Overview of Findings

The current research examined several measures of diet quality transition and how recent diet quality and long-term diet quality trends related to risk of diabetes and major cardiometabolic risk among adults in China. We used longitudinal data from the China Health and Nutrition Survey (CHNS), a large cohort study including a diverse sample with a wide range of diet data, socio-demographic, and lifestyle factors between 1991 and 2011, as well as biomarker data obtained from fasting blood samples collected in 2009. This research focused on all adults aged 18 to 65 in the CHNS and the study sample vary across aims.

We first constructed China dietary quality index (CDQI) from the diet recommendations of the 2007 CDG and tailored the AHEI-2010 (named as tAHEI) for Chinese diet. Then we examined the association between diet quality as assessed by the CDQI and tAHEI score in 2006 with risk of type 2 diabetes, prediabetes, elevated blood pressure, and lipid-related cardiometabolic risk in 2009 among Chinese adults aged 18 to 65 across 3 years of the China Health and Nutrition Survey (CHNS). We further investigated socioeconomic disparity in 20-year diet quality transition from 1991 to 2011. We performed longitudinal quantile regression models to investigate shifts in tAHEI scores at different percentiles and used mixed-effect linear random intercept regression to evaluate sociodemographic disparity in average diet quality transition. Finally, we investigated the association of baseline diet quality and annual changes in diet quality from 1991 to 2006 with diabetes-related biomarkers in 2009, including fasting glucose, hemoglobin A1c (HbA1c), insulin, homeostasis model of insulin resistance (HOMA-IR) and diabetes prevalence. A brief summary and synthesis of our findings are provided below.

Diet Quality and Risk of Diabetes and Cardiometabolic risk in Chinese adults

We used the extent of adherence to the 2007 Chinese Dietary Guidelines (CDG) and Harvard Healthy Eating Pyramid (HEP) to assess diet quality. Based on the diet-related recommendations of both guidance, we developed China dietary quality index (CDQI) using similar scaling method to the Alternative Healthy Eating Index-2010 (AHEI-2010) and tailored AHEI-2010 as the tAHEI to quantitatively assess diet quality. We had shown that the CDQI was moderately correlated with tAHEI scores and about one third of adults were classified uniformly by both scores. The CDQI score was negatively related to total energy intake and fat intake, while the tAHEI score was positively associated with total energy intake and fat intake.

We found that the CDQI was inversely associated with the risk of diabetes and high low-density lipoprotein cholesterol (LDL-C) in men and the tAHEI was inversely associated with the risk of high LDL-C in both men and women. However, CDQI was also positively associated with increased risk of elevated triacylglycerol (TAG) in women. Null associations were found with elevated blood pressure and low HDL-C for both index scores.

To the best of our knowledge, this is the first study to construct China DQI based on the recommendation of the 2007 CDG. It is also the first to examine the relation between adherence to Harvard Healthy Eating Pyramid and risk diabetes and major cardiometabolic risk in Chinese adults. Therefore this research filled an important gap in the literature. For a number of reasons we selected the tAHEI to use for further analysis in this research. First improved tAHEI was lined with a reduced risk of high LDL-C for both sexes and null association with other outcomes of interest in Chinese adults. In addition, it fits best with globally available diet-disease evidence and potentials of predictive effectiveness of major chronic diseases in many other population.

20-Year Diet Quality Transition in Chinese adults

We found that Chinese diet quality had improved across the entire distribution of the tAHEI scores with the most remarkable increase occurring between 2009 and 2011. The 20-year diet quality transition varied greatly across score percentiles and the adults with higher diet quality tended to have larger rate of improvement than those with lower diet quality over time. The most remarkable improvement in diet quality was mostly attributable to increased intakes of polyunsaturated fatty acids (PUFAs), eicosapntemacnioc acid (EPA) and docosahexenoic acid (DHA).

We also found different improvement profile of diet quality over time in Chinese adults as compared to that in US adults. These included a remarkable increase in PUFAs score (about 7.0 points) and long chain (ω-3) fatty acids score (about 5.3 points) in the tAHEI score, slight increase in the scores of whole fruit, nuts and legume, and slight decline in the scores of cereal fiber, sugar sweetened beverages (SSBs) and fruit juices, and red meat over time in Chinese adults over 20-year period. In contrast, US adults had slight increases in the scores of SSBs and fruit juice, whole fruit, whole grains, and nuts and legumes but slight decrease in sodium score over 12-year period.

We also examined potential difference in diet quality transition across the socio-demographic subgroups. We saw significant improvements in diet quality in all socio-demographic subpopulations, however, diet quality transition varied across income, education, urbanicity and geographic regions. The gaps in overall diet quality became wider between southern and northern adults over the 21-year period. Adults living in high-urbanized communities shifts from lowest to highest diet quality since 2004 due to larger increase during follow-up.

To date, this is the first study to investigate secular trends in the distribution of overall diet quality, assessed by adaptation version of the AHEI-2010, in a large longitudinal sample with six repeated measurements over a 21-year period in a country undergoing rapid transitions. Our findings provide insight into dynamic shifts of the Chinese diet capturing the multidimensional complexity and contribute to better understanding of key role in diet-disease relations.

The Impact of Fifteen-year trends in Diet Quality on Diabetes Prevalence among Adults

We evaluated annual changes in diet quality by calculating the difference between the scores at the end of follow-up and baseline score divided by years of follow-up. We then categorized annual changes into five levels: high decrease, low decrease, maintain, low increase and high increase. We found that baseline diet quality and annual changes in diet quality, assessed by the tAHEI score, were inversely, but not linearly, associated with insulin and HOMA-IR, but not with fasting glucose and HbA1c in Chinese adults. Annual changes in diet quality was nonlinearly and negatively associated with prevalence of fasting glucose-defined diabetes in Chinese adults, while baseline diet quality was not related to prevalence of diabetes defined by both fasting glucose and HbA1c. To our knowledge, our study is the first to relate long-term trends in diet quality to diabetes-related biomarkers in the Chinese population.

Limitations

This research has several limitations. First, only one time point of biomarker data in the 2009 CHNS makes it impossible to examine prospective associations between diet indexes and incident cardiometabolic risk factors except elevated blood pressure. Although we excluded those with known diabetes, taking diabetes medication or insulin based on the questionnaire, it is possible to have report bias.

Second, 24-hour diet recalls had limited ability to estimate usual intake of foods, especially for episodically consumed foods. Even consecutive 3-day 24-hour dietary recalls may have relatively limited correction for within-subject variation and may not fully reflect usual intake though research conducted in the 1990's showed at that use of 3 days of dietary recall reduced significantly attenuation of a diet-cardiometabolic outcome relationship[42]. Further, data in China FCT are reported for mainly raw foods, rather than for dishes/recipe basis, and composition of processed foods are very limited. It cannot take account into cooking loss when estimating the dishes.

Third, the tAHEI was tailored from the AHEI-2010 to match Chinese dietary data and was not identical to the AHEI-2010. It thus may not reflect the nature of the AHEI-2010 as a measure of overall diet quality. For example, we may have overestimated whole grain intake due to limited measurement of insoluble fiber in China FCT and use of a fiber-carbohydrate ratio for our whole grain proxy. Fatty acid composition may also be mismeasured as we linked the Chinese food composition table foods to the USDA food composition table and results on fatty acid may be different due to country-specific animal genetics and feeding and other food types and planting conditions. Further, the Chinese Food Composition Table (FCT) does not measure trans fatty acid levels, we thus omitted *trans* fat component of the AHEI-2010, whose importance is unknown in the modern Chinese diet although earlier research on edible oil composition found no trans fats in Chinese oils [86]. Previous studies showed rapid increases in the intake of edible oils in China and introduction of many new oils into the Chinese food supply in the past decade may have introduced oils which contain *trans* fatty acids.

As for the definition of whole grains, Mozaffarian et al. defined the most healthful whole grains as a ratio of less than 10:1 total carbohydrate to fiber. The amount of whole grains in Chinese adults was too small to get enough variation given that highly refined wheat, rice, or wheat- or rice-based products make up the majority of the cereal consumed in China. Moreover, the tAHEI did not consider cooking methods or eating behaviors, which may also play important roles in overall diet quality and related health outcomes. For instance, there is the potential that the Chinese practice of adding a small amount of edible oil during cooking can retrograde the rice and decrease significantly its glycemic index and hence capture some of the properties found in studies of the health effects of whole grains[96, 97]. Previous studies using the CHNS reported a marked increase in the proportion of energy from deep-fried and stir-fried foods over time.

Fourth, one inherent limitation refers to the method of index construction. The same total score may result from the sum of quite different component scores, however, different profile of component scores of the China DQI and tAHEI score may have different health effects. Moreover, the criteria for maximum and minimum score for each component is generally based on threshold effect on disease risk which is mainly derived from US research. However, it is still possible to show dose-response relationship beyond the threshold points. The current scaling method cannot account for this aspect. In addition, the development of an index usually use equal weight scaling method for each component. Does it make sense for the prevention of all chronic disease? There may be genetic reasons why Chinese might be more responsive to selected components than Americans and other western populations and require a different weighting for certain components. One recent study suggested the differences in genetic background of polyunsaturated fatty acids between Chinese and European populations.

Finally, the CHNS is an ongoing, open cohort study and it has the potential to be susceptible to selection bias. In general, this research focused on adults aged 18 to 65 at any wave. We selected different study sample serving each aim. In Aim 1, we selected adults aged 18 to 65 who had complete diet data in 2006 and anthropometry, blood pressure and biomarkers data in 2009. The adults who had diet data in 2006 but had no biomarkers data in 2009 may be different in diet and other socio-demographic and lifestyle factors from adults with complete diet and biomarkers. In Aim 2, we selected adults who had at least 2 waves of complete diet data from 1991 to 2011. The adults who had only one wave of diet data might be different from adults with at least 2 waves of diet in diet and other relevant characteristics. In Aim 3, we selected adults who had at least 2 waves of complete diet data from 1991 to 2006 and had diabetes markers in 2009. Similar to aforementioned selection bias possibly occurred.

Strengths

The rapid shifts in multi-dimension of food intakes and concurrent disease pattern dynamics necessitate research on the long-term transition of overall diet quality and its relationship with risk for chronic diseases or intermediate risk factors. By utilizing many advanced epidemiological approaches to handle unbalanced panel data, like the CHNS, we for the first time systematically studied the associations between index-based diet quality and diabetes markers and risk of major cardiometabolic risks in Chinese adults. It is also the first study to explore the way to develop China DQI based on CGD and examine the health benefit of the AHEI-2010 in Chinese population.

One key strength of our research is to make full use of repeated measurement of diet data to evaluate long-term indexes-based diet quality transition in China adults using mixed-effect regression and longitudinal quantile regression. In longitudinal mixed-effect and quantile regression analysis, survey years modeled as dummy variables contribute to discovering the uneven degree of diet quality transition over time instead of a continuous coding to only present average annual changes. To date, no study has been conducted to examine longitudinal changes in index-based diet quality in China.

Second, the interviewer-administered 24-hour dietary recalls in the CHNS are a good way to assess adherence to healthy dietary recommendations on a daily basis given its ability to capture extensive and complete information on all foods and beverages consumed, while the food frequency questionnaires (FFQ), used by Harvard' studies, are relatively crude in grouping relevant foods or food groups and relating to average single nutrient database. The average intakes from consecutive 3-day 24-hour recalls in our research can reduce the day to day variation and provide a relatively precise estimate of usual intake. In particular, the use of the individualized recipes for each household allows us to capture enormous variability in recipe composition[54]. Most importantly, the methodology for diet assessment in the CHNS has remained constant over 20 years of follow-up, while the Harvard FFQ were ever changed and updated to capture the new trends in food intake over time. It may not be precise to distinguish the real diet changes from the revised FFQ. Moreover, SSBs and fruit juice and alcohol, usually episodically consumed in Chinese diet, were the key components of the tAHEI. We used the past year FFQ of SSBs and fruit juice and alcohol to estimate their intakes instead of 24-hour recall, which may reduce possible random error. The combination of household weighing inventory of all condiments over the same three periods remedied the weakness of 24-hour recalls in collecting condiments consumption. The household salt, edible oil and other condiments consumption were calculated as the difference between the 2 weights[98]. Salt and edible oil intake for each household member was estimated based on the proportion of each member's intake of foods which contain added salt and oil, respectively. Taken together, the diet data of high quality in the CHNS provided relative precise assessment of Chinese diet quality.

Other strengths of this study include the use of previous diet quality or changes in diet to estimate prevalence of multiple health outcomes in 2009. The approximate prospective nature of diet-disease relationships has advantages over cross-sectional design and reduces the possibility of reverse association to some extent. Moreover, the CHNS allows us to adjust for a comprehensive range of potential confounders including sociodemographic factors, physical activity, smoking status and anthropometric measures.

Significance and public health impact

Our research has significant public health and research implications. On the research side, we developed CDQI based on the diet-related recommendations of the 2007 Chinese dietary guidelines and China balanced diet pagoda. The CDQI refined the evaluation of adherence to Chinese dietary guidelines by considering quality of vegetables (dark-color vs. light-color) and cereal (coarse grain) and scaling components score depending on energy intake level as compared to previous Chinese Food Pagoda score (CHFP) constructed by Yu et al. The CDQI can provide the basis of an updated index measuring adherence to the 2016 Chinese dietary guidelines. To date, there is no widely accepted single measure of overall diet quality to assure the relationship between diet, intermediate risk factors of chronic disease, and chronic disease in China. In the present study, the previously validated AHEI 2010 in many Western population, adapted to Chinese diet was applied in an attempt to evaluate long-term Chinese diet quality transition and the associations with risk of diabetes-related markers and major cardiometabolic risks in Chinese population. Even including a couple of modification, the adapted AHEI -2010 seems to be useful to show inversely moderate association with risk of high LDL-C and insulin and HOMA-IR values in Chinese adults. Using this single index, we found that Chinese diet quality is still far from optimal and there is huge room for further improvement.

On the public health side, effective measures should be taken to promote improvement of Chinese diet quality. The use of this adapted index of diet quality should be considered widely in individual, communities, clinical dieticians and public health field. More research is needed to further validate the CDQI and adapted AHEI-2010.

Future Directions

It would be beneficial to build fatty acid (including *trans* fat, PUFA, EPA and DHA) and whole grain databases into the China FCT and to reassess diet quality using evaluations relatively identical to the AHEI-2010. In addition, the latest version of the Chinese Dietary Guidelines (CDG), which will be promulgated in 2016, will refine and improve the 2007 CDG with updated scientific evidence on healthy recommendations. It would be interesting to update our CDQI from the recommendations of the 2016 CDG to examine the diet quality transition as compared to the tAHEI score transition. The dietary guidance might be more specific to the Chinese population to combat the shifts in both diets and disease patterns in China. Moreover, the 2016 CDG will issue special diet guidance for special populations, such as elders, maternal, child and adolescents. It is also of concerns to develop special CDQI separately for these subpopulations.

Limited by one measure of fasting blood sample in 2009, we only examined 15-year diet quality changes from 1991 to 2006 without covering the period of 2009 to 2011 with the jump improvement in diet quality, which may reflect special characteristics of diet quality transition relevant to health outcome. In the future, study is needed to examine the potential changes in 20-year diet quality in Chinese adults and further examine the potentially different health effect, such as obesity and hypertension, across levels of changes in diet quality.

In addition, our study cannot distinguish between prevalent and incident diabetes. The ongoing CHNS collected another wave of blood samples in 2015, study on this field using twice blood samples can fill the gap in this research. It is also noteworthy to investigate in the future the association of overall diet quality, assessed by the tAHEI score, with incident cardiometabolic risks and system inflammation. It will also be important to subject the future

CDQI to rigorous evaluation of its effects on risk of incident diabetes, cardiometabolic risks, and system inflammation in Chinese adults.

REFERENCES

1 World Health Organization. Global status report on noncommunicable disease 2010. 2011. Available at: http://www.who.int/nmh/publications/ncd_report_full_en.pdf (Accessed Feb 29th 2016).

2 Popkin BM, Gordon-Larsen P. The nutrition transition: worldwide obesity dynamics and their determinants. *International journal of obesity* 2004; **28:** S2-S9. doi: 10.1038/sj.ijo.0802804

3 Popkin BM. Global nutrition dynamics: the world is shifting rapidly toward a diet linked with noncommunicable diseases. *Am J Clin Nutr* 2006; **84**(2)**:** 289-298. e-pub ahead of print 2006/08/10;

4 Popkin BM, Adair LS, Ng SW. Global nutrition transition and the pandemic of obesity in developing countries. *Nutr Rev* 2012; **70**(1)**:** 3-21. e-pub ahead of print 2012/01/10; doi: 10.1111/j.1753-4887.2011.00456.x

5 WHO Expert Consultation. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet* 2004; **363**(9403)**:** 157-163. e-pub ahead of print 2004/01/17; doi: S0140-6736(03)15268-3 [pii] 10.1016/S0140-6736(03)15268-3

6 Chan JC. Diabetes in Asia: from understanding to action. *Ann Acad Med Singapore* 2008; **37**(11)**:** 903-905. e-pub ahead of print 2008/12/17;

7 Yan S, Li J, Li S, Zhang B, Du S, Gordon-Larsen P *et al.* The expanding burden of cardiometabolic risk in China: the China Health and Nutrition Survey. *Obesity reviews : an official journal of the International Association for the Study of Obesity* 2012. e-pub ahead of print 2012/06/29; doi: 10.1111/j.1467-789X.2012.01016.x

8 Gordon-Larsen P, Adair LS, Meigs JB, Mayer-Davis E, Herring A, Yan S *et al.* Discordant Risk: Overweight and cardiometabolic risk in Chinese adults Gordon-Larsen: Overweight and Cardiometabolic Risk in China. *Obesity* 2012. e-pub ahead of print 2012/06/21; doi: 10.1038/oby.2012.152

9 Willett WC, McCullough ML. Dietary pattern analysis for the evaluation of dietary guidelines. *Asia Pac J Clin Nutr* 2008; **17 Suppl 1:** 75-78. e-pub ahead of print 2008/05/28;

10 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. doi: 10.1111/obr.12124

11 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:** 60-67. doi: 10.1111/obr.12120

12 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. *Social science & medicine* 2009; **68**(7)**:** 1305-1314. doi: 10.1016/j.socscimed.2009.01.035

13 Ng SW, Howard, Annie-Green, Wang, Huijun, Su, Chang, Zhang, Bing. The Physical Activity Transition among adults in China: 1991-2011. *Obes Rev* 2014; **15 Suppl 1:** 27-36. doi: 10.1111/obr.12127

14 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 = Zhonghua liuxingbingxue zazhi* 2015; **36**(3)**:** 232-236.

15 Wang ZH, Zhai FY, Wang HJ, Zhang JG, Du WW, Su C *et al.* Secular trends in meat and seafood consumption patterns among Chinese adults, 1991-2011. *European journal of clinical nutrition* 2015; **69**(2)**:** 227-233. doi: 10.1038/ejcn.2014.225

16 Kant AK. Dietary patterns: biomarkers and chronic disease risk. *Appl Physiol Nutr Metab* 2010; **35**(2)**:** 199-206. e-pub ahead of print 2010/04/13; doi: 10.1139/H10-005

17 Kant AK. Dietary patterns and health outcomes. *J Am Diet Assoc* 2004; **104**(4)**:** 615-635.

18 Jacques PF, Tucker KL. Are dietary patterns useful for understanding the role of diet in chronic disease? *Am J Clin Nutr* 2001; **73**(1)**:** 1-2. e-pub ahead of print 2000/12/22;

19 Newby PK, Tucker KL. Empirically derived eating patterns using factor or cluster analysis: a review. *Nutr Rev* 2004; **62**(5)**:** 177-203. e-pub ahead of print 2004/06/24;

20 Hu FB. Dietary pattern analysis: a new direction in nutritional epidemiology. *Curr Opin Lipidol* 2002; **13**(1)**:** 3-9. e-pub ahead of print 2002/01/16;

21 Moeller SM, Reedy J, Millen AE, Dixon LB, Newby PK, Tucker KL *et al.* Dietary patterns: challenges and opportunities in dietary patterns research an Experimental Biology workshop, April 1, 2006. *Journal of the American Dietetic Association* 2007; **107**(7)**:** 1233-1239. e-pub ahead of print 2007/07/03; doi: 10.1016/j.jada.2007.03.014

22 Waijers PM, Feskens EJ, Ocke MC. A critical review of predefined diet quality scores. *The British journal of nutrition* 2007; **97**(2)**:** 219-231. doi: 10.1017/S0007114507250421

23 Mozaffarian D, Hao T, Rimm EB, Willett WC, Hu FB. Changes in diet and lifestyle and long-term weight gain in women and men. *The New England journal of medicine* 2011; **364**(25)**:** 2392-2404. e-pub ahead of print 2011/06/24; doi: 10.1056/NEJMoa1014296

24 Willett W. *Eat, Drink, and Be Healthy: The Harvard Medical School Guide to*

Healthy Eating, Free press, 2005.

25 Harvard School of Public Health. The Long Road to the 2010 Dietary Guidelines for Americans. *http://www.hsph.harvard.edu/nutritionsource* 2011.

26 McCullough ML, Stampfer MJ. The Dietary Guidelines for Americans and cancer risk in women: still a long way to go. *Am J Clin Nutr* 2002; **76**(4)**:** 701-702. e-pub ahead of print 2002/09/27;

27 Chiuve SE, Fung TT, Rimm EB, Hu FB, McCullough ML, Wang M *et al.* Alternative dietary indices both strongly predict risk of chronic disease. *The Journal of nutrition* 2012; **142**(6)**:** 1009-1018. doi: 10.3945/jn.111.157222

28 McCullough ML, Willett WC. Evaluating adherence to recommended diets in adults: the Alternate Healthy Eating Index. *Public Health Nutr* 2006; **9**(1A)**:** 152-157.

29 McCullough ML, Feskanich D, Rimm EB, Giovannucci EL, Ascherio A, Variyam JN *et al.* Adherence to the Dietary Guidelines for Americans and risk of major chronic disease in men. *Am J Clin Nutr* 2000; **72**(5)**:** 1223-1231.

30 McCullough ML, Feskanich D, Stampfer MJ, Giovannucci EL, Rimm EB, Hu FB *et al.* Diet quality and major chronic disease risk in men and women: moving toward improved dietary guidance. *Am J Clin Nutr* 2002; **76**(6)**:** 1261-1271.

31 McCullough ML, Feskanich D, Stampfer MJ, Rosner BA, Hu FB, Hunter DJ *et al.* Adherence to the Dietary Guidelines for Americans and risk of major chronic disease in women. *Am J Clin Nutr* 2000; **72**(5)**:** 1214-1222.

32 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**(5)**:** 1150-1156. doi: 10.2337/dc10-2352

33 Akbaraly TN, Singh-Manoux A, Tabak AG, Jokela M, Virtanen M, Ferrie JE *et al.* Overall diet history and reversibility of the metabolic syndrome over 5 years: the Whitehall II prospective cohort study. *Diabetes care* 2010; **33**(11)**:** 2339-2341. e-pub ahead of print 2010/07/31; doi: 10.2337/dc09-2200

34 Akbaraly TN, Ferrie JE, Berr C, Brunner EJ, Head J, Marmot MG *et al.* Alternative Healthy Eating Index and mortality over 18 y of follow-up: results from the Whitehall II cohort. *Am J Clin Nutr* 2011; **94**(1)**:** 247-253. e-pub ahead of print 2011/05/27; doi: 10.3945/ajcn.111.013128

35 Reedy J, Krebs-Smith SM, Miller PE, Liese AD, Kahle LL, Park Y *et al.* Higher Diet Quality Is Associated with Decreased Risk of All-Cause, Cardiovascular Disease, and Cancer Mortality among Older Adults. *The Journal of nutrition* 2014. doi: 10.3945/jn.113.189407

36 Schwingshackl L, Hoffmann G. Diet quality as assessed by the Healthy Eating Index, the Alternate Healthy Eating Index, the Dietary Approaches to Stop Hypertension score, and health outcomes: a systematic review and meta-analysis of cohort studies. *Journal of the Academy of Nutrition and Dietetics* 2015; **115**(5)**:** 780-800 e785. doi: 10.1016/j.jand.2014.12.009

37 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. *The Journal of nutrition* 2014; **144**(4)**:** 511-518. doi: 10.3945/jn.113.187955

38 China Nutrition Society. *Dietary guidelines for Chinese Residents*, 1st edn Tibet People's Publishing House: Lhasa, 2010.

39 Skrondal SR-HaA. *Multilevel and Longitudinal Modeling Using Stata*, Second edn Stata press, 2005.

40 CPC-UNC. China Health and Nutrition Survey. *Carolina Population Center, UNC-CH* 2011**:** (also available from: http//:www.cpc.unc.edu/china).

41 Jones-Smith JC, Popkin BM. Understanding community context and adult health changes in China: development of an urbanicity scale. *Social science & medicine* 2010; **71**(8)**:** 1436-1446. e-pub ahead of print 2010/09/03; doi: 10.1016/j.socscimed.2010.07.027

42 Paeratakul S, Popkin BM, Kohlmeier L, Hertz-Picciotto I, Guo X, Edwards LJ. Measurement error in dietary data: implications for the epidemiologic study of the diet-disease relationship. *European journal of clinical nutrition* 1998; **52**(10)**:** 722-727.

43 Batis C, Gordon-Larsen P, Cole S, Du S, Zhang B, Popkin B. Sodium intake from various time-frames and incident hypertension among Chinese adults. *Epidemiology* 2013; **In press**.

44 He K, Du S, Xun P, Sharma S, Wang H, Zhai F *et al*. Consumption of monosodium glutamate in relation to incidence of overweight in Chinese adults: China Health and Nutrition Survey (CHNS). *Am J Clin Nutr* 2011; **93**(6)**:** 1328-1336. doi: 10.3945/ajcn.110.008870

45 Fung TT, McCullough M, van Dam RM, Hu FB. A prospective study of overall diet quality and risk of type 2 diabetes in women. *Diabetes care* 2007; **30**(7)**:** 1753-1757. e-pub ahead of print 2007/04/13;

46 Zamora D, Gordon-Larsen P, He K, Jacobs DR, Jr., Shikany JM, Popkin BM. Are the 2005 Dietary Guidelines for Americans Associated With reduced risk of type 2 diabetes and cardiometabolic risk factors? Twenty-year findings from the CARDIA study. *Diabetes care* 2011; **34**(5)**:** 1183-1185. e-pub ahead of print 2011/04/12; doi:

10.2337/dc10-2041

47 Zamora D, Gordon-Larsen P, Jacobs DR, Jr., Popkin BM. Diet quality and weight gain among black and white young adults: the Coronary Artery Risk Development in Young Adults (CARDIA) Study (1985-2005). *Am J Clin Nutr* 2010; **92**(4)**:** 784-793. e-pub ahead of print 2010/08/06; doi: 10.3945/ajcn.2010.29161

48 Yan S, Li J, Li S, Zhang B, Du S, Gordon-Larsen P *et al.* The expanding burden of cardiometabolic risk in China: the China Health and Nutrition Survey. *Obes Rev* 2012; **13**(9)**:** 810-821. doi: 10.1111/j.1467-789X.2012.01016.x

49 Adair LS, Gordon-Larsen P, Du SF, Zhang B, Popkin BM. The emergence of cardiometabolic disease risk in Chinese children and adults: consequences of changes in diet, physical activity and obesity. *Obes Rev* 2014; **15 Suppl 1:** 49-59. doi: 10.1111/obr.12123

50 Yang ZJ, Liu J, Ge JP, Chen L, Zhao ZG, Yang WY *et al.* Prevalence of cardiovascular disease risk factor in the Chinese population: the 2007-2008 China National Diabetes and Metabolic Disorders Study. *European heart journal* 2012; **33**(2)**:** 213-220. doi: 10.1093/eurheartj/ehr205

51 Willett WC, Stampfer MJ. Current evidence on healthy eating. *Annual review of public health* 2013; **34:** 77-95. doi: 10.1146/annurev-publhealth-031811-124646

52 Ge K. The transition of Chinese dietary guidelines and food guide pagoda. *Asia Pac J Clin Nutr* 2011; **20**(3)**:** 439-446. e-pub ahead of print 2011/08/24;

53 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. *International journal of epidemiology* 2010; **39**(6)**:** 1435-1440. doi: 10.1093/ije/dyp322

54 Popkin BM, Lu B, Zhai F. Understanding the nutrition transition: measuring rapid dietary changes in transitional countries. *Public Health Nutr* 2002; **5**(6A)**:** 947-953. doi: 10.1079/PHN2002370

55 Yang Y, Wang G, Pan X. *China Food Composition Table 2009*, 2nd edn Peking University Medical Press: Beijing, 2009.

56 Ahuja J, Montville J, Omolewa TG, Heendeniya K, Martin C, Steinfeldt L *et al.* USDA Food and Nutrient Database for Dietary Studies, 5.0. USDA. 2014. Available at: http://www.ars.usda.gov/ba/bhnrc/fsrg).

57 USDA Agricultural Research Service. USDA National Nutrient Database for Standard Reference, release 25 2014. Available at: http://www.ars.usda.gov/ba/bhnrc/ndl).

58 China Nutrition Society. *Chinese residents' dietary reference intakes*, 1st edn China Light Industry Press: Beijing, 2002.

59 Mozaffarian RS, Lee RM, Kennedy MA, Ludwig DS, Mozaffarian D, Gortmaker SL. Identifying whole grain foods: a comparison of different approaches for selecting more healthful whole grain products. *Public Health Nutr* 2013; **16**(12)**:** 2255-2264. doi: 10.1017/S1368980012005447

60 Wang Z, Zhai F, Wang H, Zhang J, Du W, Su C *et al*. Trends in meat and seafood consumption patterns among Chinese adults from 1991 to 2011. *European journal of clinical nutrition* 2014.

61 Tuan NT, Adair LS, Stevens J, Popkin BM. Prediction of hypertension by different anthropometric indices in adults: the change in estimate approach. *Public health nutrition* 2010; **13**(5)**:** 639-646. e-pub ahead of print 2009/09/18; doi: 10.1017/S1368980009991479

62 Alberti KG, Zimmet P, Shaw J. Metabolic syndrome--a new world-wide definition. A Consensus Statement from the International Diabetes Federation. *Diabetic medicine : a journal of the British Diabetic Association* 2006; **23**(5)**:** 469-480. doi: 10.1111/j.1464-5491.2006.01858.x

63 Yu Y, Ouyang XJ, Lou QL, Gu LB, Mo YZ, Ko GT *et al.* Validity of glycated hemoglobin in screening and diagnosing type 2 diabetes mellitus in Chinese subjects. *The Korean journal of internal medicine* 2012; **27**(1)**:** 41-46. doi: 10.3904/kjim.2012.27.1.41

64 Yang C, Liu Y, Li X, Liang H, Jiang X. Utility of hemoglobin A1c for the identification of individuals with diabetes and prediabetes in a Chinese high risk population. *Scandinavian journal of clinical and laboratory investigation* 2012; **72**(5)**:** 403-409. doi: 10.3109/00365513.2012.689324

65 Jones-Smith JC, Popkin BM. Understanding community context and adult health changes in China: development of an urbanicity scale. *Social science & medicine* 2010; **71**(8)**:** 1436-1446. doi: 10.1016/j.socscimed.2010.07.027

66 Du S, Batis C, Wang H, Zhang B, Zhang J, Popkin BM. Understanding the patterns and trends of sodium intake, potassium intake, and sodium to potassium ratio and their effect on hypertension in China. *Am J Clin Nutr* 2014; **99**(2)**:** 334-343. doi: 10.3945/ajcn.113.059121

67 Zhang JG, Wang ZH, Wang HJ, Du WW, Su C, Zhang J *et al.* Dietary patterns and their associations with general obesity and abdominal obesity among young Chinese women. *European journal of clinical nutrition* 2015. doi: 10.1038/ejcn.2015.8

68 Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ *et al*. Compendium of physical activities: an update of activity codes and MET intensities.

Med Sci Sports Exerc 2000; **32**(9 Suppl)**:** S498-504.

69 Jacobs S, Harmon BE, Boushey CJ, Morimoto Y, Wilkens LR, Le Marchand L *et al.* A priori-defined diet quality indexes and risk of type 2 diabetes: the Multiethnic Cohort. *Diabetologia* 2014. doi: 10.1007/s00125-014-3404-8

70 Hu FB, van Dam RM, Liu S. Diet and risk of Type II diabetes: the role of types of fat and carbohydrate. *Diabetologia* 2001; **44**(7)**:** 805-817.

71 Riserus U, Willett WC, Hu FB. Dietary fats and prevention of type 2 diabetes. *Progress in lipid research* 2009; **48**(1)**:** 44-51. doi: 10.1016/j.plipres.2008.10.002

72 Ascherio A, Katan MB, Zock PL, Stampfer MJ, Willett WC. Trans fatty acids and coronary heart disease. *N Engl J Med* 1999; **340**(25)**:** 1994-1998. doi: 10.1056/NEJM199906243402511

73 Wang DD, Leung CW, Li Y, Ding EL, Chiuve SE, Hu FB *et al.* Trends in dietary quality among adults in the United States, 1999 through 2010. *JAMA internal medicine* 2014; **174**(10)**:** 1587-1595. doi: 10.1001/jamainternmed.2014.3422

74 Wang ZH, Siega-riz AM, Gordon-Larsen P, Cai JW, Adair LS, Zhang B *et al.* Diet Quality and the Risk of Type 2 Diabetes and Major Cardiometabolic Risk Factors among Adults in China. *(in press)* 2015.

75 Wang Z, Zhang B, Wang H, Zhang J, Du W, Su C *et al.* Study on the multilevel and longitudinal association betweend meat consumption and changes in body mass index, body weight and risk of incident overweight among Chinese adults. *Chin J Epidemiol* 2013; **34**(7)**:** 1-7.

76 Tee ES. Development and promotion of Malaysian Dietary Guidelines. *Asia Pac J Clin Nutr* 2011; **20**(3)**:** 455-461. e-pub ahead of print 2011/08/24;

77 Cole TJ, Freeman JV, Preece MA. British 1990 growth reference centiles for weight, height, body mass index and head circumference fitted by maximum penalized likelihood. *Statistics in medicine* 1998; **17**(4)**:** 407-429.

78 Koenker R. Quantile Regression for Longitudinal Data. *Journal of Multivariate Analysis* 2004; **91:** 74-89.

79 Koenker R, Bassett G. Regression quantile. *Econometrica* 1978; **46:** 33-50.

80 Du S, Mroz TA, Zhai F, Popkin BM. Rapid income growth adversely affects diet quality in China--particularly for the poor! *Social science & medicine* 2004; **59**(7)**:** 1505-1515. doi: 10.1016/j.socscimed.2004.01.021

81 Wang Z, Zhai F, He Y, Wang H. Influence of family income on dietary nutrients intake and dietary structure in China. *Wei sheng yan jiu = Journal of hygiene research*

2008; **37**(1)**:** 62-64.

82 Wang ZH, Zhai FY, Wang HJ, Zhang JG, Du WW, Su C *et al.* Influence of Household Income Level on Food Consumption in Chinese Population. *Food and Nutrition In China* 2015; **21**(3)**:** 46-49.

83 Sugiyama T, Shapiro MF. The growing socioeconomic disparity in dietary quality: mind the gap. *JAMA internal medicine* 2014; **174**(10)**:** 1595-1596. doi: 10.1001/jamainternmed.2014.3048

84 Wang HJ, Zhang B, Du WW, Liu AD, Zhang JG, Wang ZH *et al.* Trends of the dietary fiber intake among Chinese aged 18 - 45 in nine provinces (autonomous region) from 1989 to 2006. *Zhonghua yu fang yi xue za zhi [Chinese journal of preventive medicine]* 2011; **45**(4)**:** 318-322.

85 2015 Dietary Guidelines Advisory Committee. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. 2015. Available at: http://www.health.gov/dietaryguidelines/2015-scientific-report/ 2015).

86 Wallingford JC, Yuhas R, Du S, Zhai F, Popkin BM. Fatty acids in Chinese edible oils: value of direct analysis as a basis for labeling. *Food and nutrition bulletin* 2004; **25**(4)**:** 330-336.

87 Kant AK, Graubard BI. A comparison of three dietary pattern indexes for predicting biomarkers of diet and disease. *J Am Coll Nutr* 2005; **24**(4)**:** 294-303.

88 Wang Z, Zhai F, Zhang B, Popkin BM. Trends in Chinese snacking behaviors and patterns and the social-demographic role between 1991 and 2009. *Asia Pac J Clin Nutr* 2012; **21**(2)**:** 253-262.

89 Pan XR, Yang WY, Li GW, Liu J. Prevalence of diabetes and its risk factors in China, 1994. National Diabetes Prevention and Control Cooperative Group. *Diabetes care* 1997; **20**(11)**:** 1664-1669.

90 Yang W, Lu J, Weng J, Jia W, Ji L, Xiao J *et al.* Prevalence of diabetes among men and women in China. *N Engl J Med* 2010; **362**(12)**:** 1090-1101. doi: 10.1056/NEJMoa0908292

91 Chinese Diabetes Society under Chinese Medical Association. Guidelines for prevention and treatment of diabetes in China. *China J Diabetes Mellitus* 2014; **6**(7)**:** 447-498.

92 World Health Organization. *Global status report on noncommunicable diseases 2010*, World Health Organization: Geneva, 2011.

93 Harvard School of Public Health. The Long Road to the 2010 Dietary Guidelines for Americans. Available at: http://www.hsph.harvard.edu/nutritionsource/dietary-

guidelines-for-americans-2010/ (Accessed 22 September 2015).

94 Fretts AM, Howard BV, McKnight B, Duncan GE, Beresford SA, Mete M *et al.* Associations of processed meat and unprocessed red meat intake with incident diabetes: the Strong Heart Family Study. *Am J Clin Nutr* 2012; **95**(3)**:** 752-758. doi: 10.3945/ajcn.111.029942

95 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. *Annals of epidemiology* 2009; **19**(10)**:** 692-700. doi: 10.1016/j.annepidem.2009.03.019

96 Bahado-Singh PS, Riley CK, Wheatley AO, Lowe HI. Relationship between Processing Method and the Glycemic Indices of Ten Sweet Potato (Ipomoea batatas) Cultivars Commonly Consumed in Jamaica. *Journal of Nutrition & Metabolism* 2011; **2011:** : 584832.;

97 Ha AW, Han GJ, Kim WK. Effect of retrograded rice on weight control, gut function, and lipid concentrations in rats. *Nutrition research and practice* 2012; **6**(1)**:** 16-20. doi: 10.4162/nrp.2012.6.1.16

98 Zhai F, Guo X, Popkin BM, Ma L, Wang Q, Yu W *et al.* The Evaluation of the 24Hour Individual Recall Method in China. *Food & Nutrition Bulletin* 1996; **17**.