Original Article

Analysis of dietary trends in Chinese adolescents from 1991 to 2011

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Background and Objectives: To examine temporal trends in dietary energy, fat, carbohydrate, protein, sodium and potassium intake of Chinese adolescents aged 12 – 17 years by sex and urbanicity, using data from the China Health and Nutrition Survey. **Methods and Study Design:** Individual level, consecutive 3 – day 24-hour recalls were analyzed from survey years 1991 (n=504), 2000 (n=665), and 2011 (n=267) from nine provinces representing a range of geography, economic development, and health indicators in China. Linear multivariable regression models were conducted to predict mean intakes of energy, macronutrients, sodium, and potassium. Models were adjusted for age, per capita income, parental education, region, and family size. **Results:** From 1991 to 2011, total energy consumption decreased among both sexes and all urbanicity groups (p<0.05). Sodium intake decreased in all sex and urbanicity groups except the high urbanicity group, which was the only group to show significant change in potassium intake (p<0.05). Sodium-potassium ratios decreased overall and across both sexes (p<0.05). However, the major observed shift was a structural change from carbohydrates to fat and protein. Both sexes showed decrease in carbohydrate-derived energy (p<0.05). Proportion of fat-derived energy increased in female adolescents. Proportion of protein-derived energy increased in male adolescents, as well as in the low and high urbanicity groups (p<0.01). **Conclusions:** This suggests Chinese adolescents are transitioning to a low carbohydrate diet. Urbanicity appears to play a role in sodium, potassium and protein intake. Improvements of sodium-potassium ratios are primarily due to decreased sodium intake and require further reduction efforts.

Key Words: nutrition transition, China, adolescents, dietary trends, urbanicity

INTRODUCTION

China has undergone dramatic economic, demographic, and social transformations over the past few decades, including unprecedented economic growth, changes in basic family structure, and increased modernization of the Chinese food system.[1-3] These changes affect daily life in numerous ways, including adjustments in major dietary and activity patterns, which in turn impact health and health behavior.[4,5] For example, when the China Health and Nutrition Survey (CHNS) was designed in 1987–1988, China had a food rationing system defined by small, open, fresh markets with limited stores of produce and animal-sourced foods; however, an emerging modern food system with concurrent shifts in dietary intake gradually appeared.[6,7] The first Western fast food chain, Kentucky Fried Chicken, opened in 1987, and supermarkets and convenience stores started rapidly propagating in the early 2000s.[6] With changes in food availability and accessibility came a need to understand how the Chinese diet has reacted to these developments.

Recent literature shows that China has been undergoing a nutrition transition towards a “Westernized” diet, which is defined by low grain intake and high consumption of edible-oils and animal sourced foods.[6,8-12] This shift towards a higher-fat, lower-carbohydrate intake is associated with a dramatic increase in the prevalence of diet-related non-communicable diseases (DR-NCDs), such as diabetes and obesity, and has been observed in various developing nations, including India and parts of Saudi Arabia.[4,8,9,12-14] In fact, China is one of the countries with the most rapid increases in chronic diseases.[2] In 2008, dyslipidemia reached a staggering prevalence of 65% of Chinese adults surveyed from the China National Diabetes and Metabolic Disorders Study.[15] A study on Chinese children aged 7 to 17 years found that prevalence of overweight and obesity more than doubled from 5.2% in 1991 to 13.2% in 2006.[16] Other DR-NCDs, such as cardiovascular disease and cancer, are currently leading causes of death in China.[2]

To address this growing public health concern, many epidemiological studies have been conducted to better understand the changing dietary trends of the Chinese.[6,9,17,18] Most of these nutritional studies focus on adult participants, leaving a research gap on dietary trends of adolescents and children. However, adolescence is a critical period of development, and diet and eating habits that develop during these years tend to continue through adulthood.[19,20] The few studies that focus on younger age

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Manuscript received 23 November 2017. Initial review completed 04 December 2017. Revision accepted 21 January 2018.
doi: 10.6133/apjcn.042018.02

groups frequently approach their analysis with a cross-sectional methodology, undermining their ability to predict changes in dietary trends over time, and usually concentrate on narrow issues such as processed food intake.[11,19,21] Thus, longitudinal understanding of changes in adolescent dietary trends is lacking, yet imperative, for predicting imminent public health concerns and effectively tailoring nutritional interventions for future generations.

Our study aims to offer a holistic comprehension of changes in adolescent consumption by examining dietary trends through sex and urbanicity. One study in Southwest China found significant differences by sex in total energy intake, fiber intake, and dietary energy density in children 8–14 years old.[22] Additionally, urbanicity has been found to have an important influence on nutritional intake.[4,6,8,23] A study by Huang and Bouis found that in China, urbanicity alone accounted for an increased 5.7–9.3 kilograms of meat and fish consumption per capita and a decreased 58.7–70.1 kilograms of rice consumption per capita, when controlling for income and product price.[24] Sodium and potassium intakes were also included in our analysis of dietary consumption because of the important impact they have on DR-NCDs, such as stroke and other cardiovascular diseases, that are greatly prevalent and an increasing public health issue in China.

To better understand the effects of recent socioeconomic changes in China on adolescent nutrition and their potential implications, this study investigates the effect of sex and urbanicity on total energy intake, macronutrient dietary trends and changes in sodium and potassium consumption of Chinese adolescents.

METHODS

Survey design

The CHNS is an ongoing longitudinal study created to monitor and understand how socio-economic changes impact health behaviors in a rapidly developing environment. The CHNS began in 1989 and originally spanned over 8 provinces: Guangxi, Guizhou, Henan, Hubei, Hunan, Jiangsu, Liaoning, and Shandong. A ninth province, Heilongjiang, was added in 1997. These provinces vary substantially in geography, economic development, public resources, and health indicators.[12] Samples from these provinces are drawn using a multistage, random cluster process. Counties in the provinces were first stratified by income into three classes (low, medium, and high). From each province, 4 counties (one low-, two medium-, and one high-income county) were randomly selected using a weighted sample scheme that ensures adequate sample size and representation of our target population. From each county, the township capital and 3 villages, as well as 20 households from each of these communities, were randomly selected to participate in the survey. 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 household members were interviewed, and all provided written informed consent.

Data analyzed in this paper were collected from 3 survey rounds (1991, 2000, 2011). Data for the autonomous cities of Beijing, Shanghai and Chongqing were only available for 2011. We will refer to these three locations as megacities, as their population size of 20–35 million residents differs greatly from other urban or rural stratifications. Their data will be presented separately from the nine provinces. More information and detail of the CHNS can be found elsewhere.[3]

Subjects

This study surveyed a group of 1719 adolescents for dietary information, including total energy intake (kcal), carbohydrate (g) intake, fat intake (g), protein intake (g), sodium (mg), and potassium (mg) intake. Adolescence was defined in our study as children aged 12–17 y in agreement with existing studies on Chinese adolescents.[8,9,21,23,25,26] Exclusion criteria for the present analyses included missing information of the following: urbanicity (n=36), parental education (n=65), and per capita income (n=41). Additional exclusion criteria included adolescents living by themselves, thus eliminating family sizes of one (n=25). The eligible sample included 1614 adolescents of the total 1719 subjects within the target age group of 12–17 years old. Some subjects were missing more than one variable of information, so the total number of excluded participants does not equal the sum of all the excluded participants by variable.

In our analysis, sample sizes of 504, 665 and 453 subjects were drawn from survey year 1991, 2000 and 2011 respectively. The 453 subjects of the 2011 CHNS were further categorized and independently analyzed in two groups: adolescents living in the nine provinces and adolescents living in the three megacities. In total, the final sample size for the nine provinces in 2011 was 267 adolescents, and the sample size for the three megacities was 186 adolescents. Given that the survey years used in this study are approximately ten years apart and our study population spanned only six years (from twelve to seventeen years old), no participant was surveyed twice.

Dietary data

Measurement of household food inventory

Household food consumption data were collected from changes in household food inventory for three consecutive days, which were randomly allocated from Monday to Sunday. A baseline measurement of all foods (including edible oils, salt, soy sauce, and monosodium glutamate) was first collected before initiation of the survey. Household food inventory was then collected at the beginning and end of each survey day by carefully measuring all foods purchased from markets, foods produced in the home, and food preparation waste (including spoiled rice and food fed to animals) to calculate daily household food consumption. At the completion of the survey, all remaining food was weighed and recorded again.

Measurement of individual dietary intake

Individual dietary data were collected in 24–hour recalls the same 3 consecutive days as selected for measurements of household food inventory. Subjects were responsible for self-reporting all foods consumed both at home and away from home. Trained field interviewers assisted in dietary recall with the use of food models and picture aids. Records were made of type and amount of food, type of meal, and place of food preparation. Food items consumed at restaurants, canteens, and other locations away from home were recorded solely dependent on the respondent's memory, and food items consumed in the home were based on 24-hour recall for the amounts of each dish/recipe consumed. The individual foods came from the household recipes for each complex dish. Each individual's amount of that food was based on their proportion of the complex dish consumed.

Conversion to nutrients for analysis

The Chinese food composition table (FCT) was used to convert foods to their nutrient components.[27] However, the FCT is based on food as purchased and does not account for additional nutrients included in food preparation. Stir-frying, in particular, is a major cooking method for Chinese dishes, and the omission of cooking oil would greatly affect the accuracy of each dishes' nutritional composition as determined by the FCT. For this reason, a method was developed to accurately allocate cooking oil, soy sauce, and other common condiments added during cooking or eating to individual dietary intake from total household consumption. These allocations were based on the proportion of household dishes containing those items consumed by each individual or based on where those items were added during eating by each individual. The nutrient intakes over three consecutive days were summed and then divided by three to obtain the average daily nutrient consumption for each individual.

The mean daily energy intake (kcal), carbohydrate intake (g), fat intake (g), protein intake (g), sodium intake (mg) and potassium intake (mg) values were obtained from the dietary intake data collected in the CHNS, which were derived from the Chinese Food Composition Table. A food's energy value is calculated as the sum of values of all energy producing nutrients, i.e. carbohydrate, protein and fat (not including alcohol), multiplied by the corresponding energy conversion factor (1 g = 4 kcal for carbohydrate, 1 g = 4 kcal for protein and 1 g = 9 kcal for fat).[28] Proportions of energy from carbohydrates, fat and protein were obtained by dividing an individual's mean energy intake of each macronutrient by the individual's mean total energy consumption. Proportions of macronutrient energy were used in our analysis to evaluate changing dietary compositions to account for changes in total dietary intake.

Socio-demographic data

Our analysis is based on sex and urbanicity. In regards to effects of gender awareness on nutritional intake, adolescence is the developmental period where older children start to absorb various social norms as part of their self-identity.[29] Integration of new social awareness into existing beliefs and behaviors can, in turn, have major impacts on dietary pattern.

The urbanicity index used in this study diverges from the commonly applied use of population density as the determinant of urbanization. Instead, this study uses a continuous urbanicity scale developed by Jones-Smith and Popkin that is constructed from 12 holistic variables, including population density, economic activity, traditional markets, modern markets, transportation infrastructure, sanitation, communications, housing, education, diversity, health infrastructure, and social services.[30] Though this index was tested and validated on Chinese women, its strong performance on tests of internal consistency, reliability, content validity, criterion-related validity and construct validity demonstrate its usefulness and potential in other health and demographic outcomes, such as adolescence. The urbanicity index consists of a continuous scale ranging from 0 to 120 and was classified in this study by tertiles (0-52, 53-67, and 68-120) for analysis purposes.

Covariates include age, per capita income, parental education, region, and family size. Adolescents were stratified and analyzed as two age groups: 12–13 years old and 14–17 years old. Per capita income and parental education level were both categorized by tertiles (low, medium, and high). Parental education was defined by maternal education level when available. Paternal education level was supplemented as a surrogate when maternal education level was not available (n=51). Region was classified into North (Heilongjiang, Liaoning, Shandong), Central (Henan, Hubei, Jiangsu), and South (Hunan, Guizhou, Guangxi). Family size was defined with consideration to recent changes in Chinese family structure. As an indirect effect of the one-child policy enacted in China from 1979 to 2015, the Chinese family structure has shifted dramatically towards trio-based nuclear families and away from traditional multi-generational households with extended family members.[1] Consequently, we defined family size as households of 2–3 members or households of 4 or more members.

Statistical analysis

Linear regression models were constructed to predict means of total energy, macronutrients (carbohydrates, fat, and protein), sodium, potassium, and sodium-potassium ratio intakes over time within sex and urbanicity strata and adjusted for covariate sociodemographic variables, including age, per capita household income, parental education, region, and family size. Linear regression models were selected after diagnosing the linear model assumptions (existence, independence, linearity, homoscedasticity and Gaussian distribution). Furthermore, we used White´s procedure to obtain heteroscedasticity-corrected standard errors where necessary. A significance level of 0.05 was used to determine if differences were statistically significant. In the case of multiple comparisons, the Bonferroni correction was used for adjustment of the significance level. Analysis was carried out using Stata 14.1 (Stata Statistical Software, release 14.1; StataCorp).

RESULTS

Table 1 presents the study population's major characteristics, including age, sex, urbanicity index, per capita income, parental education, region, and family size. In regards to the nine provinces, the sample size was 504 in 1991, 665 in 2000, 267 in 2011, respectively. The mean age and standard deviation (SD) was 14.9 (SD ±1.78), 14.4 (SD ±1.61), and 14.6 (SD ±1.66) in 1991, 2000, and 2011, respectively. The 3 megacities had a mean age of 15.1 (SD ±1.75), with age ranging between 12.0 to 18.0 years. In all survey years of the nine provinces, there

Table 1. Characteristics of the study sample, China Health and Nutrition Survey 1991–2011

	1991	2000	2011	3 megacities
Sample (n)	504	665	267	186
Age (n)				
12 to 13 y	188 (37.3%)	305 (45.9%)	116 (43.4%)	61 (32.8%)
14 to 17 y	316 (62.7%)	360 (54.1%)	151 (56.6%)	125 (67.2%)
Male (n, %)	261 (51.8%)	405 (60.9%)	163 (61.0%)	93 (50.0%)
Urbanicity Index (%)				
Low	325 (64.5%)	294 (44.2%)	56 (21.0%)	
Medium	128 (25.4%)	107 (16.1%)	55 (20.6%)	
High	51 (10.1%)	264 (39.7%)	156 (58.4%)	
Per capita income†				
Overall (mean±SD)	2860±1870	5440±4390	13800±15900	17000±14900
Low (mean±SD)	1920±862	2010±933	1610±1210	
Medium (mean±SD)	4440±630	4590±694	4740±627	
High (mean±SD)	7740±1900	9390±4770	17600±17000	
Parental education				
Low	392 (53.8%)	80 (20.0%)	32 (10.4%)	
Medium	260 (35.7%)	205 (51.3%)	200 (65.1%)	
High	77 (10.6%)	115 (28.8%)	75 (24.4%)	
Region				
North	109 (21.6%)	269 (40.5%)	83 (31.1%)	
Central	199 (39.5%)	183 (27.5%)	77 (28.8%)	
South	196 (38.9%)	213 (32.0%)	107 (40.1%)	
Family Size				
2 to 3	143 (28.4%)	390 (58.6%)	164 (61.4%)	
4+	361 (71.6%)	275 (41.4%)	103 (38.6%)	

†Values are means and standard deviation measured in renminbi.

were slightly more male than female participants (52% in 1991, 61% in 2000, 61% in 2011). In the megacity population, there was an even distribution of male and female participants. The average urbanicity of the study population increased steadily in the nine provinces; the number of participants in the low urbanicity tertile decreased from 65% to 21% while the number of participants in the high urbanicity tertile increased from 10% to 58% from 1991 to 2011. Family size shifted from primarily 4 or more household members (72% in 1991) to family sizes of 2 or 3 (61% in 2011).

Nutrient trends

Table 2 presents unadjusted rates of macronutrient energy intake and sodium-potassium consumption for comparison against the three megacities. In the nine provinces, there was a rapid increase in fat-derived energy intake from 22% in 1991 to 32% in 2011. Additionally, there was an important decrease in energy intake from carbohydrates (67% to 55%) and increase in energy intake from proteins (12% to 13%). The three megacities of Shanghai, Beijing, and Chongqing displayed an energy composition of 37% fat, 47% carbohydrate, and 16% protein. In the overall sample, sodium intake has dramatically decreased from 7900 mg/d in 1991 to 4300 mg/d in 2011 (Table 2). Potassium intake decreased from 1700 mg/d in 1991 to 1400 mg/d in 2000 and increased back to 1700 mg/d in 2011 — a U-shaped, nonlinear trend that yields an overall insignificant change from 1991 to 2011.

Predicted mean intakes of dietary energy, macronutrient energy, sodium, potassium and sodium-potassium ratios are presented in Table 3, and the resulting beta coefficients are presented in Supplemental Tables 1-3. Corresponding visual displays for predicted mean intakes of dietary energy, sodium, potassium and sodium-potassium ratios are found in Figure 1. Figure 2a and Figure 2b display macronutrient energy as proportions of total energy intake by urbanicity index and sex, respectively. In the overall sample of Chinese adolescents, we observed decreases in total energy intake, sodium intake, sodium-potassium ratios, and proportion of energy from carbohydrate and increases in proportion of energy from fat and protein intake from 1991 to 2011 ($p<0.01$) (Table 3).

Energy intake among Chinese adolescents steadily decreased from 2520 kcal in 1991 to 1860 kcal in 2011 ($p<0.01$) after adjusting for covariates. Declines were also

Table 2. Macronutrient composition of dietary energy and micronutrients in Chinese adolescents, unadjusted

	1991	2000	2011	Three mega cities
Macronutrients				
% energy from fat	21.9	28.3	31.8	36.6
% energy from carbohydrates	66.6	59.5	54.6	47.1
% energy from protein	11.5	12.2	13.4	16.2
Micronutrients				
Sodium g/d	7.9	5.9	4.3	4.3
Potassium g/d	1.7	1.4	1.7	1.6
Sodium/potassium ratio	5.0	4.2	2.9	2.9

Figure 1. Dietary Energy, Sodium, and Potassium Intakes and Sodium–Potassium Ratios (Na/K) in Chinese adolescents by Sex and Urbanicity Index from 1991 to 2011.

observed when evaluated by sex and by urbanicity. It is worth noting that the greatest decline in energy intake was observed in the low urbanicity group (801 kcal/d) and was more than double the decline observed in the high urbanicity group (375 kcal/d).

The proportion of fat energy increased in our survey population from 24.7% in 1991 to 28.0% in 2011 (p<0.01). Proportion of fat energy increased in females, but not males, and showed no significant change when evaluated by urbanicity. For female adolescents, fat-derived energy increased from 25.0% in 1991 to 29.5% in 2011 (p<0.01). In contrast, the proportion of dietary energy provided by carbohydrates decreased for Chinese adolescents overall and when evaluated by sex (p<0.01). Overall proportion of carbohydrate energy decreased from 63.2% to 59.0% (p<0.01). Proportion of protein energy increased from 12.0% to 12.9% (p<0.01). Analysis by sex and urbanicity also displayed significant increases in protein-derived energy in the male, low urbanicity, and high urbanicity groups (p<0.01).

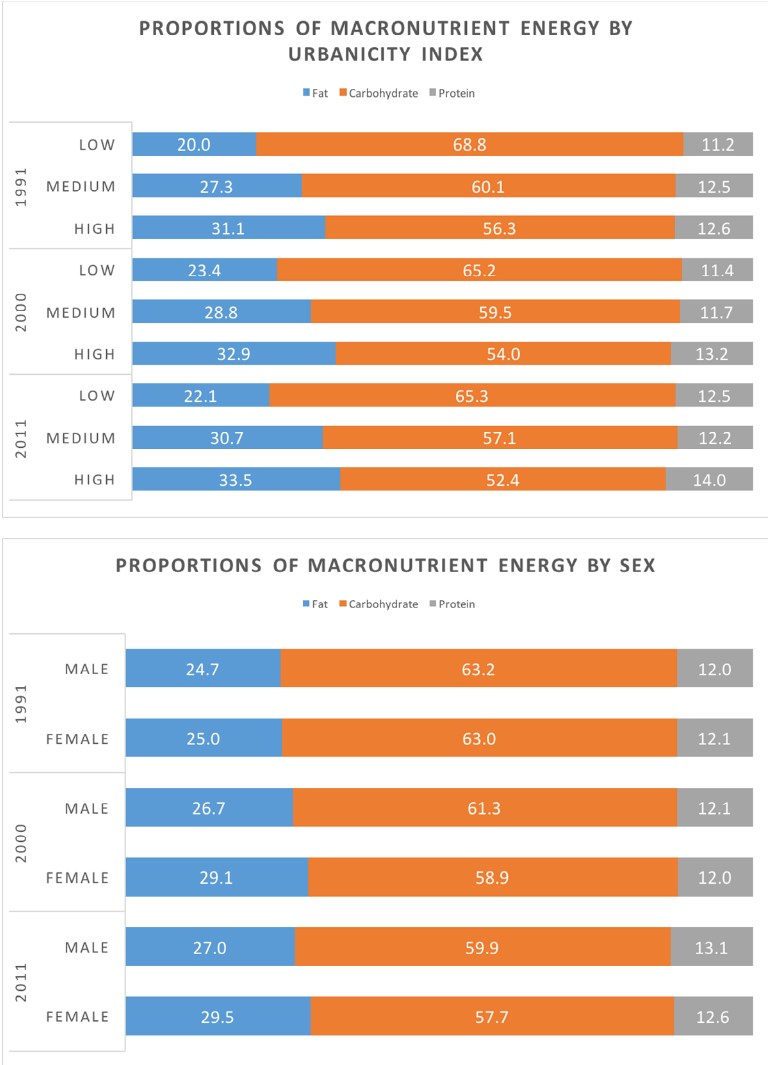

Figure 2. (a) Proportions of energy from fat, carbohydrate, and protein in Chinese adolescents from 1991 to 2011 stratified by urbanicity index. (b) Proportions of energy from fat, carbohydrate, and protein in Chinese adolescents from 1991 to 2011 stratified sex.

Sodium intake decreased across all sex and urbanicity groups from 1991 to 2011, except for the high urbanicity group (p<0.05) (Table 3). In contrast, potassium intake only increased in the high urbanicity group (p<0.01) and yielded no changes in the other urbanicity tertiles or when analyzed by sex. All of the groups except the high urbanicity group showed decreases in potassium intake from 1991 to 2000 (p<0.05). The net result of these changes in sodium and potassium consumption is a decrease in sodium-potassium ratio from 5.0 in 1991 to 3.0 in 2011 in our overall sample population (p<0.01). The largest change was observed in the low urbanicity group, which decreased from a sodium-potassium ratio of 5.5 to 2.3 (p<0.01) (Table 3).

DISCUSSION

Our study indicates that Chinese adolescents are continuing a trend of decreasing energy intake with major shifts in the structure of their diet away from high carbohydrates toward higher fat and protein. Additionally, there is continued overconsumption of sodium and high levels of sodium-potassium ratios despite significant declines in sodium intake. This rapid nutrition transition mirrors trends seen in Chinese adults over the last two decades and has contributed to the rising significance of DR-NCDs as a leading public health issue.[31,32]

Energy intake

Though energy density has increased steadily from 1991 to 2011 — a result of the increasing Westernization of Chinese diets, total energy intake has counterintuitively decreased in this same time period.[10,22,33] Indeed, a number of clinical studies finds that increases in energy density should increase, not decrease, total energy intake.[34,35] We postulate that urbanization may account for this observation of decreasing energy intake, specifically through mechanisms of decreasing physical activity, increasing levels of underreporting, and increased protein consumption.[8,33,36-42]

With urbanization has come rapid integration of technology into everyday life.[33] Increased use of technology in work, transportation, and entertainment has led to decreased levels of physical activity.[8,33,36] If adolescents are moving less, then they are decreasing their energy needs and may be consequently consuming fewer calories. Our study finds that low-urbanicity adolescents had the greatest decrease in total energy intake, more than double the decrease observed in high-urbanicity adolescents. This

Table 3. Trends in Dietary Energy, Macronutrient, and Sodium, Potassium, and Sodium–Potassium Ratio in Chinese adolescents by sex and urbanicity index

	1991		2000		2011		Linear trend
	Mean	SE	Mean	SE	Mean	SE	*p* value
Dietary energy (kcal)							
All	2520	32	2110†	25	1860†,‡	42	<0.001
Sex							
Male	2620	45	2230†	32	1990†,‡	56	<0.001
Female	2380	44	1950†	39	1680†,‡	65	<0.001
Urbanicity							
Low	2570	41	2090†	38	1760†	86	<0.001
Medium	2400	59	2070†	59	1780†	91	<0.001
High	2340	79	2170	36	1960†,‡	46	<0.001
Fat energy (%)							
All	24.7	0.5	27.7†	0.4	28.0†	0.7	<0.001
Sex							
Male	24.7	0.7	26.7†	0.5	27.0	0.9	0.049
Female	25.0	0.8	29.1†	0.7	29.5†	1.2	0.001
Urbanicity							
Low	20.0	0.6	23.4†	0.6	22.1	1.5	0.010
Medium	27.3	1.0	28.8	1.0	30.7	1.5	0.076
High	31.1	1.4	32.9	0.6	33.5	0.9	0.219
Carbohydrate energy (%)							
All	63.2	0.5	60.3†	0.4	59.0†	0.7	<0.001
Sex							
Male	63.2	0.7	61.3†	0.5	59.9†	0.9	0.005
Female	63.0	0.7	58.9†	0.7	57.7†	1.2	<0.001
Urbanicity							
Low	68.8	0.6	65.2†	0.6	65.3	1.6	0.002
Medium	60.1	0.9	59.5	0.9	57.1	1.4	0.111
High	56.3	1.4	54.0	0.6	52.4†	0.8	0.024
Protein energy (%)							
All	12.0	0.1	12.1	0.1	12.9†,‡	0.2	<0.001
Sex							
Male	12.0	0.2	12.1	0.1	13.1†,‡	0.2	<0.001
Female	12.1	0.2	12.0	0.1	12.6‡	0.2	0.102
Urbanicity							
Low	11.2	0.1	11.4	0.1	12.5†,‡	0.3	0.001
Medium	12.5	0.2	11.7	0.2	12.2	0.4	0.307
High	12.6	0.4	13.2	0.2	14.0†,‡	0.2	<0.001
Sodium (mg)							
All	7900	285	5940†	224	4400†,‡	383	<0.001
Sex							
Male	8060	372	5980†	269	4320†,‡	465	<0.001
Female	7660	441	5940†	390	4550†	651	<0.001
Urbanicity							
Low	8530	413	5350†	417	3710†	1010	<0.001
Medium	7180	481	6420	485	4750†	745	0.014
High	5900	566	6370	239	4520‡	319	<0.001
Potassium (mg)							
All	1720	35	1540†	27	1690‡	47	<0.001
Sex							
Male	1770	47	1600†	34	1770‡	59	<0.001
Female	1640	52	1450†	56	1580	93	0.011
Urbanicity							
Low	1750	40	1580†	57	1550	104	0.264
Medium	1650	61	1410†	61	1470	94	0.045
High	1540	97	1560	41	1840†,‡	55	0.099
Sodium–potassium ratio							
All	5.0	0.2	4.2†	0.2	3.0†,‡	0.3	<0.001
Sex							
Male	4.9	0.2	4.0†	0.2	2.6†,‡	0.3	<0.001
Female	5.1	0.4	4.5	0.3	3.5†	0.6	0.027
Urbanicity							
Low	5.5	0.3	3.8†	0.3	2.3†	0.8	<0.001
Medium	4.5	0.3	5.0	0.3	3.4	0.5	0.108
High	3.8	0.4	4.3	0.2	2.9‡	0.2	<0.001

†Significance between survey year 1991 and 2000 or 2011 (using Bonferroni adjustment),
‡Significance between survey year 2000 and 2011 (using Bonferroni adjustment)

suggests that early stages of urbanization, in particular through introduction of new technologies, may indeed play a significant role in decreasing physical activity and energy consumption.

Another potential explanation for the observed decrease in energy intake is under-reporting of energy consumption. Though under-reporting is not well studied in children and adolescents, the few studies that have been conducted find a positive association of under-reporting with the female sex, low socioeconomic status, overweight status, lower contribution of simple carbohydrates in diet, higher contribution of proteins in diet, and skipping breakfast and dinner.[37-41] Most of these determinants of health behavior, such as decreasing carbohydrate intake and increasing prevalence of overweight status, are currently underway in China's nutrition transition, which itself is influenced by China's rapid urbanization. This implies that under-reporting may be an amplified issue in future studies as China continues to globalize and develop. More research is needed to confirm this trend in developing nations, as much existing literature is based in developed nations or on small sample populations.

High protein consumption has been shown to be associated with inhibition of energy intake through greater satiating efficacies than those of other macronutrients.[9,43-45] It is reasonable to conclude that as China's urbanization propels a nutrition transition toward greater protein intake, such as through rising availability and consumption of animal-sourced foods, increased protein intake may contribute to observed decreases in energy intake.[9] Thus, another mechanism through which urbanization may induce decreasing energy intake in Chinese adolescents is rising protein consumption.

A trend of decreasing total energy intake is consistent with findings in many other developing nations, including Jordan, Mexico, South Korea, Egypt, Thailand, and Indonesia.[46-53] However, there are some developing nations that demonstrate an opposite trend in energy intake.[54-56] These inconsistencies might be explained, in part, by different stages of economic development or different methods of estimating dietary intake.[8] In the CHNS, the same method of collecting dietary intake was used in all surveys.

The consumption of energy intake was higher in males than in females during the three survey years under study, and this difference increased over time. To some degree, this gap in energy consumption can be explained biologically, as adolescent males and females are different in their body composition. Males have more lean muscle mass than their female counterparts, and thus higher resting energy expenditures.[57-59] However, it is also well supported in the literature that sociocultural influences are potent influencers of body change behavior. The message and impact of these influences vary greatly by sex, which consequently promotes distinctive health behaviors and ideals between males and females.[60] For example, compared to their male counterparts, females engage in less physical activity, have greater body consciousness and fear of fatness, and are more susceptible to special dietary behaviors attempting to decrease their weight.[22,57,58] As China continues her trend of globalization, there is greater adoption of Western body ideals by mass media and older relatives that further promote body dissatisfaction and body change behaviors among Chinese adolescents.[42,60,61] Thus, the increasing difference in energy intake by sex may be fostered by the adoption of western body image ideals, such as extreme muscularity in males and glamorized thinness in females.[60]

Macronutrients

The proportion of energy from fat has increased considerably in Chinese adolescents over the past two decades. The proportion of energy from carbohydrates has decreased steadily in that same period. These findings are consistent with the high energy density characteristic of Westernized diets and of China's current nutrition transition, as a shift from carbohydrates to fats would make diets inherently higher in energy density.[6,8-12]

The proportion of energy from protein increased slightly in Chinese adolescents overall, as well as within the male, low urbanicity and high urbanicity groups. The rise in protein energy is likely associated with China's rapid growth over the past few decades and its effect on consumption of animal-sourced foods. Urbanization increases access and affordability of animal-source foods, as well as promotes greater consumption of food prepared outside the home, of which animal source food is a key component.[9,62] Studies have found urban areas consume significantly more protein from animal-sourced foods, including meat, eggs, and milk, than their rural counterparts.[9,18] Indeed, per capita calorie consumption of meat products alone has increased more than 15 times from 1961 to 2003, and one study on Chinese children aged 6 to 17 years found that median total meat intake increased from 47.4 g/d in 1991 to 100 g/d in 2011.[63,64] Thus, urbanization appears to play an important role in the rise of animal-based protein consumption.

Sodium-Potassium

It is interesting to note the dramatic change in sodium consumption from 1991 to 2011 given the concurrent minor changes in potassium consumption. A potential explanation for this difference is that the Chinese public may be generally unaware of, and thus less proactive in addressing, the extreme lack of potassium in their normal diet.[65,66] Sodium, on the other hand, is given much public and governmental attention in China. For example, healthcare reforms from 2009 offer free blood pressure checks and partially subsidized drugs for hypertension patients in efforts to reach a nationwide goal of reducing salt intake from an average of 12 g/d in rural communities to 9 g/d across the country by 2015.[17,67] Additionally, rising ownership of household refrigeration has decreased the necessity and use of salt as a food preservative, further contributing to the observed decline in salt consumption. These governmental efforts and social changes are reflected in our findings, as we observed decreased sodium consumption across all sex and urbanicity groups, except for the high urbanicity group. This exception could be attributed to the greater availability of packaged foods in urban areas compared to rural ones. Processed food intake is a rapidly growing source of dietary sodium, tripling in Chinese adults from 1.8% of sodium intake in 1991 to 6.8% in 2009.[17] More research is needed to specifically identify major sources of sodium intake in Chinese children and adolescents.

However, despite these declines, sodium consumption levels among Chinese adolescents are still much higher than the Institute of Medicine's recommendation of <2200 mg/d and <2300 mg/d for 9–13 and 14–18 years old, respectively.[68] Potassium similarly continues to miss intake guidelines set by the Institute of Medicine; Chinese adolescents are obtaining less than half the recommended >4500 mg/d and >4700 mg/d for 9–13 and 14–18 years old, respectively.[68] Driven primarily by decreasing sodium consumption, sodium-potassium ratios decreased from 1991 to 2011 when evaluated by either sex or by the low urbanicity group, but no significant changes were seen in the medium and high urbanicity groups. All groups' sodium-potassium ratios remain above recommended levels and require further reduction efforts in Chinese adolescents.

There is dramatic variation in sodium-potassium ratio trends between the low urbanicity group and the medium and high urbanicity groups. The medium and high urbanicity groups show very similar, U-shaped trends, but the low urbanicity group demonstrates nearly linear decline. Additionally, the low urbanicity group starts with the highest values in both sodium intake and sodium-potassium ratio in 1991 and falls to the lowest levels in 2011. This suggests that the impact of continued urbanization differs greatly based on a region's current level of urban development. Specifically, we postulate that urbanization may provoke a faster rate of decreasing sodium consumption in low urbanicity areas as compared to rates in medium or high urbanicity areas. Existing literature shows that there are differences in sodium consumption behaviors among urban and rural populations, such as the practice of salting vegetables for food preservation in rural communities when refrigerators are not available or affordable.[17,67] If urbanization at the low urbanicity level promotes widespread purchasing of newly affordable refrigerators, there may be a faster decline in sodium intake at the low urbanicity level than at the medium or high urbanicity level, where there is likely a higher prevalence of household refrigerators. Indeed, the prevalence of refrigerator ownership in China increased dramatically from 16.6.% in 1991 to 63.7% in 2009.[17] However, there is a gap in the literature on factors, such as the prevalence of household refrigerator purchases in different urban settings, that may contribute to differences in sodium intake between more rural and more urban areas. No studies currently exist that analyze rate of sodium reduction by urbanicity. More research is needed to understand this relationship between urbanicity and changes in sodium intake.[17,67]

To further support the premise that urbanization plays an important factor in sodium intake, one study identified an inverse relationship between total sodium, salt, and soy sauce intake and level of education in Chinese adults.[67] This finding has not been extrapolated into adolescents, as there are fewer differences in adolescent education levels than in adult counterparts, but it does suggest that parents' education may play an important factor in an adolescent's sodium intake. Education is one of the twelve determinants included in the urbanicity index used in this study, with higher education levels indicating more urban areas. However, this is representative of the average education level among all adults aged 18 and older, not just parents with adolescent children.[30] As such, we additionally included parental education as an important covariate in our study to account for any possible effects of parent education on adolescent dietary intake. Additionally, many researchers find grandparents are playing a greater role than previously expected.[69-71] A relationship between parent education and sodium intake suggests that China may observe further decreases in sodium intake with continued urbanization.

Decrease in sodium intake is associated with decreased prevalence of hypertension; however, cases of prehypertension and hypertension have increased 8.13% in Chinese adolescents from 1991 to 2004.[17,72] Hypertension is the major risk factor for stroke and heart disease, which now accounts for up to 56% of total deaths in some of China's major cities.[17,67] We conclude that interventions to combat this major public health issue cannot merely target salt intake reduction, but must also address other known causes of hypertension, such as obesity, smoking and low potassium intake from inadequate fruit and vegetable consumption.

Comparison to the megacities

In comparison to the dietary trends observed across the nine provinces, the dietary intakes of the three megacities show striking similarities. The three megacities present energy compositions higher in fat, lower in carbohydrates, and higher in protein. The proportions of energy derived from each macronutrient are extrapolations of the macronutrient trends already observed in the nine provinces, suggesting that these trends may continue across China with continued economic development and urbanization.

Strengths and limitations

Among the multiple strengths integrated into this study, the most prominent is the use of multiple, cross-sectional survey years in our dietary analysis. Many earlier studies that explore dietary intake in Chinese adolescents focus on a single, cross-sectional population, thus limiting their ability to draw longitudinal conclusions. By studying the same age population over two decades, our study can observe trends in dietary intake to better understand the relationship of diet with socioeconomic factors and predict future health implications.

One limitation to this study comes from the CHNS's utilization of the Chinese FCTs.[27] The Chinese FCT does not include any recipes, so measurement of away-from-home food intake must rely on knowledge of the ingredients used in food preparation. Furthermore, current food composition tables assume identical composition for select dishes in home and restaurant preparations, when in actuality, there is enormous variability in nutrient content of dishes and their food components.[73] The 2015 and future CHNS surveys will use an augmented process to collect dishes that will allow a better understanding of the average components of current dishes consumed in China. One recently published analysis compares dishes prepared at home, in stalls, and at sit-down restaurants in one city and one rural area to understand differences between away-from-home and at-home food preparation.[42,60,61,73]

Additionally, because our study analyzes total consumption of each macronutrient and micronutrient, we are limited in our ability to draw conclusions regarding the changes in the types of foods consumed. For example, the decreasing proportion of carbohydrate energy observed in this study is simultaneous with a shift in grain consumption from coarse grains towards refined grains shown through other studies on Chinese adolescents.[6] Similarly, the rise in proportion of fat energy observed in this study could be attributed to increased consumption of edible oil and animal sourced foods, especially in the form of snacks and food consumed away from home.[6] However, these more nuanced analyses are beyond the scope of this paper.

One final limitation in this study is the restricted sample size of the nine provinces in the 2011 CHNS. Relative to the sample sizes in the 1991 and 2000 survey years (n=504 and n=665, respectively), the 2011 sample size (n=267) is notably smaller. This is largely in part to many village schools closing and relocating students to town schools—a government initiative that occurred concurrently with the initiation of the 2011 CHNS and thus inhibited data collection. Though tolerable, the resulting smaller sample population creates potential for skewed representation and analysis.

Conclusion

Chinese adolescents have been in a state of nutrition transition towards a high-fat, low-carbohydrate diet for the past two decades, which has promoted the rising prevalence of DR-NCDs. Total dietary intake has decreased steadily across both sexes and all urbanicity groups. Despite decreased sodium consumption among Chinese adolescents, sodium intake and sodium-potassium ratios are still above recommended levels, and improvements in sodium-potassium ratios alone are not enough to effectively combat major cardiovascular diseases. Future studies should analyze how rates of dietary trends, such as decreasing sodium consumption, differ by urbanicity with a focus on low-urbanicity communities versus medium- and high-urbanicity communities. Future studies should also aim to identify the food sources responsible for observed dietary trends, such as decreasing sodium intake or decreasing carbohydrate consumption. Continued evaluation of the effects of urbanization, such as decreased physical activity and increased adoption of Western social norms, on adolescent dietary intake is necessary to appropriately tailor future nutritional interventions.

ACKNOWLEDGEMENTS

I would like to acknowledge the various individuals and institutions that have supported me in the completion of this paper. First, I owe a debt of gratitude to my graduate student mentor, Nancy, who has patiently and tirelessly served as an indispensable source of information and motivational support. Second, my research would not have been possible without the collaboration between the Carolina Population Center at the University of North Carolina at Chapel Hill and the National Institute for Nutrition and Health at the Chinese Center for Disease Control and Prevention. Finally, I would like to express sincere gratitude and appreciation to my thesis advisor, Dr. Barry Popkin, who has given me invaluable guidance and encouragement throughout these past two years and has served as an incredible role model in the field of epidemiology.

AUTHOR DISCLOSURES

This research uses data from China Health and Nutrition Survey (CHNS). We thank The National Institute for Nutrition and Health, China Center for Disease Control and Prevention. We are also grateful for funding from the NIH to Carolina Population Center at the University of North Carolina at Chapel Hill (NIH grant P2C HD050924, T32 HD007168) and to research grants from the NIH (R01 HD30880, P30 DK056350, R01 HD38700, and the NIH Fogarty grant D43 TW009077 for financial support for the CHNS data collection and analysis files from 1989 to 2015 and future surveys, and the China-Japan Friendship Hospital, and Ministry of Health for support for CHNS 2009. We wish to thank Ms. Frances Dancy Burton for administrative assistance, Ms. Guifeng Jin for data base assistance, and Ms. Denise Ammons for graphics support and research assistance.

We are also grateful for funding from the Tom and Elizabeth Long Excellence Fund in support of this research project. None of the authors has conflict of interests of any type with respect to this manuscript.

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Supplemental table 1. Differences in intakes of dietary energy, macronutrient energy, sodium, potassium, and sodium-potassium ratio in 2000 and 2011 in comparison with 1991 (n=1,436)

Variable	1991 (n=504)					2000 (n=665)					2011 (n=267)				
	β	SE	*p*	Low CI	High CI	β	SE	*p*	Low CI	High CI	β	SE	*p*	Low CI	High CI
Dietary energy (kcal)				Ref		-413	42	<0.001	-495	-331	-668	57	<0.001	-780	-555
Fat energy (%)				Ref		2.93	0.68	<0.001	1.60	4.27	3.27	0.93	<0.001	1.45	5.10
Carbohydrate energy (%)				Ref		-2.92	0.68	<0.001	-4.25	-1.59	-4.15	0.92	<0.001	-5.96	-2.34
Protein energy (%)				Ref		0.06	0.16	0.72	-0.26	0.37	0.87	0.22	<0.001	0.43	1.30
Sodium (mg)				Ref		-1960	380	<0.001	-2700	-1210	-3500	519	<0.001	-4520	-2490
Potassium (mg)				Ref		-182	47	<0.001	-274	-91	-32	64	0.61	-157	92
Sodium-potassium ratio				Ref		-0.78	0.28	0.01	-1.33	-0.24	-2.03	0.38	<0.001	-2.77	-1.28

Supplemental table 2. Differences in intakes of dietary energy, macronutrient energy, sodium, potassium, and sodium-potassium ratio in 2000 and 2011 in comparison with 1991 by sex (n=1,436)1potassium ratio in 2000 and 2011 in comparison with 1991 by sex (n=1,436)

Variable	1991					2000					2011				
	β	SE	*p*	Low CI	High CI	β	SE	*p*	Low CI	High CI	β	SE	*p*	Low CI	High CI
Male (n=829)															
Dietary energy (kcal)				Ref		-395	57	<0.001	-507	-283	-635	78	<0.001	-788	-482
Fat energy (%)				Ref		2.00	0.88	0.02	0.27	3.72	2.31	1.20	0.06	-0.05	4.66
Carbohydrate energy (%)				Ref		-1.97	0.88	0.03	-3.69	-0.24	-3.35	1.20	0.01	-5.71	-1.00
Protein energy (%)				Ref		0.10	0.22	0.65	-3.29	0.53	1.12	0.30	<0.001	0.53	1.71
Sodium (mg)				Ref		-2080	474	<0.001	-3010	-1150	-3740	648	<0.001	-5020	-2470
Potassium (mg)				Ref		-173	60	0.004	-291	-56	2.90	82	0.97	-157	163
Sodium-potassium ratio				Ref		-0.83	0.27	0.002	-1.37	-0.29	-2.28	0.37	<0.001	-3.02	-1.55
Female (n=607)															
Dietary energy (kcal)				Ref		-432	62	<0.001	-554	-309	-706	85	<0.001	-872	-539
Fat energy (%)				Ref		4.08	1.09	<0.001	1.94	6.22	4.55	1.48	0.002	1.65	7.45
Carbohydrate energy (%)				Ref		-4.04	1.07	<0.001	-6.15	-1.94	-5.24	1.46	<0.001	-8.11	-2.38
Protein energy (%)				Ref		-0.04	0.24	0.88	-0.51	0.43	0.57	0.32	<0.001	-0.07	1.21
Sodium (mg)				Ref		-1720	627	0.01	-2950	-486	-3110	851	<0.001	-4780	-1440
Potassium (mg)				Ref		-192	75	0.01	-338	-45	-66	101	0.51	-266	133
Sodium-potassium ratio				Ref		-0.66	0.55	0.23	-1.73	0.42	-1.66	0.74	0.03	-3.12	-0.20

Supplemental table 3. Differences in intakes of dietary energy, macronutrient energy, sodium, potassium, and sodium-potassium ratio in 2000 and 2011 in comparison with 1991 by urbanicity index (n=1,436)

Variable	1991					2000					2011				
	β	SE	*p*	Low CI	High CI	β	SE	*p*	Low CI	High CI	β	SE	*p*	Low CI	High CI
Low Urbanicity Index (n=675)															
Dietary energy (kcal)				Ref		-479	60	<0.001	-597	-362	-800	110	<0.001	-1020	-585
Fat energy (%)				Ref		3.44	0.93	<0.001	1.60	5.27	2.12	1.72	0.22	-1.25	5.50
Carbohydrate energy (%)				Ref		-3.51	0.94	<0.001	-5.35	-1.67	-3.41	1.72	0.05	-6.80	0.02
Protein energy (%)				Ref		0.17	0.19	0.36	-0.20	0.54	1.32	0.34	<0.001	0.65	1.99
Sodium (mg)				Ref		-3190	622	<0.001	-4410	-1960	-4820	1150	<0.001	-7070	-2570
Potassium (mg)				Ref		-164	67	0.01	-296	-33	-196	123	0.11	-438	46
Sodium-potassium ratio				Ref		-1.74	0.47	<0.001	-2.67	-0.81	-3.18	0.87	<0.001	-4.89	-1.47
Medium Urbanicity Index (n=290)															
Dietary energy (kcal)				Ref		-332	88	<0.001	-504	-159	-618	118	<0.001	-851	-385
Fat energy (%)				Ref		1.50	1.43	0.30	-1.33	4.32	3.41	1.93	0.08	-0.39	7.21
Carbohydrate energy (%)				Ref		-0.64	1.36	0.64	-3.33	2.05	-3.06	1.84	0.10	-6.68	0.57
Protein energy (%)				Ref		-0.08	0.36	0.02	-1.54	-0.12	-0.37	0.49	0.45	-1.32	0.59
Sodium (mg)				Ref		-761	716	0.29	-2170	649	-2430	965	0.01	-4330	-526
Potassium (mg)				Ref		-240	91	0.01	-418	-62	-179	122	0.14	-419	61
Sodium-potassium ratio				Ref		0.45	0.45	0.32	-0.43	1.33	-1.16	0.60	0.06	-2.34	0.03
High Urbanicity Index (n=471)															
Dietary energy (kcal)				Ref		-166	91	0.07	-345	14	-376	99	<0.001	-570	-181
Fat energy (%)				Ref		1.82	1.59	0.26	-1.31	4.95	2.42	1.72	0.16	-0.97	5.80
Carbohydrate energy (%)				Ref		-2.35	1.59	0.14	-5.48	0.78	-3.90	1.72	0.02	-7.28	-0.51
Protein energy (%)				Ref		0.59	0.43	0.18	-0.27	1.44	1.42	0.47	0.003	0.49	2.34
Sodium (mg)				Ref		467	615	0.45	-741	1680	-1380	665	0.04	-2690	-72
Potassium (mg)				Ref		15	106	0.89	-193	223	295	114	0.01	70	520
Sodium-potassium ratio				Ref		0.51	0.42	0.23	-0.32	1.34	-0.89	0.46	0.053	-1.78	0.01