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**Abstract**

**Objective**: To examine temporal trends in dietary energy, carbohydrate, fat, and protein intake, and sodium and potassium intake of Chinese adolescents aged 12 – 17 years by sex and urbanicity, using data from the China Health and Nutrition Survey (CHNS).

**Methods**: Individual level, consecutive 3 – day 24 hour recalls were analyzed from survey years 1991 (n=489), 2000 (n=677), and 2011 (n=253) from nine provinces that represent a range of geography, economic development, public resources, and health indicators in China. Linear multivariable regression models were conducted to predict the mean intake of energy, macronutrients, sodium and potassium. Models were adjusted for age, per capita income, mother's education, region, and family size.

**Results**: Intakes of total energy, sodium, and sodium-potassium ratio decreased from 1991 to 2011 ($p<0.01$) among both sexes and all urbanicity groups; however, the major shift was a structural change from carbohydrates to fat and protein. Both sexes showed decrease in carbohydrate-derived energy and increase in fat-derived energy ($p<0.05$). Increase in protein intake was only significant in the male and high-urbanicity groups ($p<0.01$). Changes in potassium intake were only observed in the high urbanicity group ($p<0.01$).

**Conclusions**: This data suggest that Chinese adolescents are undergoing a transition to a high fat diet, independent of sex or urbanicity. Urbanicity appears to play a role in protein and potassium intake. Improvements of sodium-potassium ratios seem primarily due to decrease in sodium intake and require further reduction efforts.

## 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 (Chen 1985, Wang, Mi et al. 2007, Zhang, Zhai et al. 2014). These changes affect daily life in numerous ways, including adjustments in major dietary and activity patterns, which in turn impact health and health behavior (Popkin 2006, Popkin 2017). 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 (Du, Wang et al. 2014, Zhai, Du et al. 2014); however, an emerging modern food system with concurrent shifts in dietary intake gradually appeared. The first Western fast food chain, Kentucky Fried Chicken (KFC) opened in 1987, and supermarkets and convenience stores started rapidly propagating in the early 2000s (Zhai, Du et al. 2014). With changes in food availability and accessibility came a new 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 (Popkin, Keyou et al. 1993, Du, Lu et al. 2002, Li, Dibley et al. 2010, Cui and Dibley 2012, Du, Wang et al. 2014, Zhai, Du et al. 2014). 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 (Popkin, Keyou et al. 1993, Du, Lu et al. 2002, Popkin 2006, Cui and Dibley 2012, Gordon-Larsen, Wang et al. 2014, Shaikh 2016). In fact, China is one of the countries with the most rapid increases in chronic diseases (Wang, Mi et al. 2007). In 2008, dyslipidemia reached a staggering prevalence of 65% in Chinese adults surveyed from the China National Diabetes and Metabolic Disorders Study (Yang, Liu et al. 2011). A report released in 2011 by the Chinese Capital Institute of Pediatrics revealed that 20% of youths in Beijing were overweight or obese, a rate five to seven times greater than from 20 years prior (B. Jing et al.). Other DR-NCDs, such as cardiovascular disease and cancer, are currently leading causes of death in China (Wang, Mi et al. 2007).

To address this growing public health concern, many epidemiological studies have been conducted to better understand the changing dietary trends of the Chinese (Qu, Zhang et al. 2000, Du, Lu et al. 2002, Du, Neiman et al. 2014, Zhai, Du et al. 2014). However, most of these nutritional studies focus on adult participants, leaving a research gap on dietary trends of adolescents and children. The few studies that focus on younger age groups tend to 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 (Li, Dibley et al. 2010, Zhang, Chen et al. 2012, Wang, Shi et al. 2014). Adolescence is a critical period of development, and diet and eating habits that develop during these years tend to continue through adulthood (Debby Demory-Luce , Wang, Shi et al. 2014). Thus, a longitudinal understanding of changes in adolescent dietary trends is imperative for predicting imminent public health concerns and effectively tailoring nutritional interventions for future generations. 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 the macronutrient dietary trends and changes in sodium and potassium consumption of Chinese adolescents.

## Subjects and 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 (Popkin, Keyou et al. 1993). 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, middle, and high). From each province, 4 counties (one low-, two middle-, and one high-income county) were randomly selected using a weighted sample scheme. 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 (Zhang, Zhai et al. 2014).

Subjects

This study surveyed a group of 3252 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 (Du, Lu et al. 2002, Shi, Lien et al. 2005, Ong, Meng et al. 2010, Cui and Dibley 2012, Zhang, Chen et al. 2012, Niu, Seo et al. 2014). Exclusion criteria for the present analyses included missing information of the following: urbanicity (n = 69), region (n = 348), mother's education (n=1617), and per capita income (n = 79). Tests on the impact of the large proportion of households with missing mother's education are addressed in the discussion. Additional exclusion criteria included adolescents living by themselves, thus eliminating family sizes of one (n = 49). The eligible sample included 1581 adolescents of the total 3252 subjects within the target age group of 12 – 17 year olds. 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 the analysis of the nine provinces, sample sizes of 489, 677, and 253 subjects were drawn from survey year 1991, 2000 and 2011 respectively. An additional 162 participants came from the three megacities, which were only surveyed in 2011, and are analyzed separately from the nine provinces. Given the survey years used in this study, 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 MSG) 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. All subjects were responsible for self-reporting all foods consumed both at home and away from home. Trained field interviewers aided in dietary recall via 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 (recipe). Each individual's amount of that food was based on their proportion of the complex dish (recipe) consumed.

*Conversion to Nutrients for Analysis*

The Chinese food composition table (FCT) was used to convert foods to their nutrient components. 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. Each resident's intake of the nutrients for three consecutive days was 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). Proportions of energy from carbohydrates, fat and protein were obtained by dividing individual energy intake of each macronutrient by an 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. Additionally, sodium and potassium intakes were 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.

Socio-Demographic Data

Our analysis is based on sex and urbanicity. Adolescence is the developmental period where older children start to absorb various social norms as part of their self-identity (Lagaert, Van Houtte et al. 2017). Integration of new social awareness into existing beliefs and behaviors has major impacts on dietary pattern. One study in Southwest China found significant differences by sex in total energy intake, fiber intake, and dietary energy density (Zhou, Xue et al. 2015). Urbanicity is another important factor already well-supported in the literature to influence nutritional intake (Shi, Lien et al. 2005, Popkin 2006, Cui and Dibley 2012, Zhai, Du et al. 2014). 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 (Huang and Bouis 2004).

The urbanicity index used in this study diverges from the commonly used method of population density as a determination of urbanization. Instead, a continuous urbanicity scale developed by Jones-Smith and Popkin was used 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 (Jones-Smith and Popkin 2010). This continuous scale was classified by tertiles for analysis purposes.

Covariates include age, per capita income, mother's education, region, and family size. Adolescents were stratified and analyzed as two age groups: 12 – 14 year olds and 14 – 17 year olds. Per capita income and maternal education were both categorized by tertiles (low, middle, and high). 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 (Chen 1985). Consequently, we defined family size binomially as households of 2 – 3 members or households of 4 or more members.

<u>Statistical Analysis</u>

Linear regression models were constructed to predict means of macronutrients (carbohydrates, fat, and protein), sodium, potassium, and sodium-potassium ratio intakes by sex and urbanicity and adjusted for covariate sociodemographic variables, including age, per capita household income, mother's education, region, and family size. 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, mother's education, region, and family size. The sample size was 489 in 1991, 677 in 2000, 253 in 2011, respectively. The mean age was 14.89 (SD ± 1.78), 14.36 (SD ± 1.78), and 14.61 (SD ± 1.63) in 1991, 2000, and 2011, respectively. The 3 megacities had a mean age of 15.16 (SD ± 1.62), with age ranging from 12.08 to 17.98 years. In all survey years of the 9 provinces, as well as for the megacity population, there were slightly more male than female participants (51.3% in 1991, 61.2% in 2000, 59.7% in 2011, and 51.2% in the 3 megacities). The average urbanicity of the study population increased steadily in the 9 provinces; the number of participants in the low urbanicity tertile decreased from 47.6% to 10.8% while the number of participants in the high urbanicity tertile increased from 7.6% to 32.1% from 1991 to 2011. Family size shifted from primarily 4 or more household members (72% in 1991) to family sizes of 2 or 3 (60% 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 9 provinces, there was a rapid increase in energy intake from fat from 22.1% in 1991 to 31.7% in 2011. Additionally, there was an important decrease in energy intake from carbohydrates (66.4% to 54.8%) and increase in energy intake from proteins (11.50% to 13.5%). The three megacities of Shanghai, Beijing, and Chongqing displayed an energy composition of 46% carbohydrate, 37% fat, and 17% protein. In the overall sample, sodium intake has dramatically decreased from 7900 mg $d^{-1}$ in 1991 to 4400 mg $d^{-1}$ in 2011 (Table 2). Potassium intake decreased from 1700 mg $d^{-1}$ in 1991 to 1500 mg

$d^{-1}$ in 2000 and increased back to 1700 mg $d^{-1}$ in 2011 — a U-shaped, nonlinear trend that yields an overall insignificant change from 1991 to 2011. A closer analysis of sodium and potassium intake reveals that sodium intake decreased across all sex and urbanicity groups (p<0.01) (Table 3). In contrast, potassium intake only increased in the high urbanicity group and yielded no changes in the other urbanicity tertiles or when analyzed by sex from 1991 to 2011 (p<0.01). All of the groups except the high urbanicity group showed decreases in potassium intake from 1991 to 2000 (p<0.01). The net result of these changes in sodium and potassium intake is a decreased sodium-potassium ratio from 5.0 in 1991 to 2.9 in 2011 (p<0.01). The largest change was observed in the low urbanicity group, which decreased from a sodium-potassium ratio of 5.6 to 1.6 (p<0.01) (Table 3).

In our overall sample, we observed decreases in total energy intake, proportion of energy from carbohydrate, and Na/K ratios and increases in proportion of energy from fat intake and proportion of energy from protein intake from 1991 to 2011 ($p < 0.01$) (Table 3).

Energy intake among Chinese adolescents steadily decreased from 2523.7 kcal in 1991 to 1856.7 kcal in 2011 (p<0.01) after adjusting for covariates. Differences were observed by sex in total energy intake (236 kcal/d in 1991, 260 kcal/d in 2000, and 368 kcal/d in 2011) across all survey years, respectively (p<0.01). It is worth noting that the decline in energy intake in the low urbanicity group (774.4 kcal/d) was more than double the decline observed in the high urbanicity group (355.7 kcal/d).

Similarly, the proportion of dietary energy provided by carbohydrates decreased for Chinese adolescents across all sex and urbanicity groups (p<0.01). Overall proportion of carbohydrate energy decreased from 63.3% to 59.2% (p<0.01). Differences in proportion of carbohydrate energy between low and high urbanicity groups (69.2% to 60.4% in 1991, 62.5% to

55.8% in 2000, and 59.5% to 53.2% in 2011) were observed across all survey years, respectively ($p<0.01$). Contrary to the declining trends in total energy intake and carbohydrate energy, the proportion of fat energy increased from 24.7% in 1991 to 27.9% 2011 ($p<0.01$). Proportion of fat energy increased when evaluated by sex, but showed no significant change when evaluated by urbanicity ($p<0.01$). Female adolescents had the greatest increase in fat-derived energy, from 24.8% in 1991 to 29.1% in 2011 ($p<0.01$). The low and high urbanicity groups showed significant differences in proportion of fat-derived energy (19.7% to 27.1% in 1991, 25.7% to 31.3% in 2000, and 27.6% to 32.8% in 2011) across all survey years, respectively ($p<0.01$). Overall, the proportion of protein energy increased from 12.0% to 12.9% ($p<0.01$). Analysis by sex and urbanicity groups displayed a significant increase of protein-derived energy in the male and high urbanicity groups only ($p<0.01$).

**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 proportions of energy from 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 has occurred concurrently over the last two decades with China’s extraordinary economic development and has contributed to the rising significance of DR-NCDs as a leading public health issue.

*Energy Intake*

Though energy density has increased steadily from 1991 to 2011 — a result of the increasing Westernization of Chinese diets (Popkin 2002, Du, Wang et al. 2014, Zhou, Xue et al. 2015), total energy intake has counterintuitively decreased in this same time period. Indeed, a number of clinical studies find that increases in energy density should increase, not decrease, total energy intake (Bell, Castellanos et al. 1998, Drewnowski 1998). We postulate that urbanization may account for this observation, specifically through mechanisms of decreasing physical activity and increasing levels of underreporting (Schoeller 1990, Livingstone, Prentice et al. 1992, Champagne, Delany et al. 1996, Sichert-Hellert, Kersting et al. 1998, Popkin 2002, Popkin, Lu et al. 2002, Lioret, Touvier et al. 2011, Cui and Dibley 2012, Ng and Popkin 2012). With urbanization has come rapid integration of technology into everyday life (Popkin 2002). Increased use of technology in work, transportation, and entertainment have led to decreased levels of physical activity (Popkin 2002, Cui and Dibley 2012, Ng and Popkin 2012). If adolescents are not moving as much as they used to move, then they are decreasing their energy needs and may be consequently consuming less, thus resulting in the observed decrease in total energy intake. Our study finds that low-urbanicity adolescents had the greatest decrease in total energy intake, nearly double the decrease observed in high-urbanicity adolescents, suggesting that urbanization and its role in spreading new technologies does indeed play a significant role in energy consumption.

Another potential explanation for the observed decrease in energy intake is under-reporting of energy intake in adolescents. Though under-reporting is not well studied in children and adolescents, the few studies that have been conducted find an association of under-reporting with the female sex, low socioeconomic status, overweight status, lower contribution of simple carbohydrates in diet, higher contribution of proteins to diet, and skipping breakfast and dinner (Schoeller 1990, Livingstone, Prentice et al. 1992, Champagne, Delany et al. 1996, Sichert-Hellert, Kersting et al. 1998, Lioret, Touvier et al. 2011). 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, implying that under-reporting may be an amplified issue in future studies. More research is needed to confirm these trends in developing nations, as much existing literature is based in developed nations or on small sample populations.

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 (Kim, Moon et al. 2000, Galal 2002, Kosulwat 2002, Rivera, Barquera et al. 2002, Shetty 2002, Lee and Sobal 2003, Lipoeto, Wattanapenpaiboon et al. 2004, Madanat, Troutman et al. 2008). However, there are some developing nations that demonstrate an opposite trend in energy intake (Albala, Vio et al. 2002, Benjelloun 2002, Noor 2002). These inconsistencies might be explained, in part, by different stages of economic development or different methods of estimating dietary intake (Cui and Dibley 2012). In the CHNS, the same method of collecting dietary intake was used in all surveys.

The gap in energy intake between males and females was distinct and increasing across all three survey years, from 236.4 kcal in 1991 to 367.7 kcal in 2011. This difference by sex can, to some degree, be explained biologically, as adolescent males and females are different in their body composition. Males have more lean muscle mass than their female counterparts; therefore, males have higher resting energy expenditures (Kirchengast and Marosi 2008, Geer and Shen 2009, Zhang, Yao et al. 2012). 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 (Xu, Mellor et al. 2010). 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 (Kirchengast and Marosi 2008, Geer and Shen 2009, Zhou, Xue et al. 2015). 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 (Popkin, Lu et al. 2002, Chen and Jackson 2009, Xu, Mellor et al. 2010). 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 (Xu, Mellor et al. 2010).

*Macronutrients*

The proportion of energy from carbohydrates has decreased steadily in Chinese adolescents from 63.3% to 59.2% over the past two decades. Concurrently, the proportion of energy from fat has increased considerably from 24.7% to 27.9%. 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 (Popkin, Keyou et al. 1993, Du, Lu et al. 2002, Li, Dibley et al. 2010, Cui and Dibley 2012, Du, Wang et al. 2014, Zhai, Du et al. 2014).

The proportion of energy from protein increased slightly from 12.0% to 12.9% from 1991 to 2011. Plant-based foods used to be the major protein source in Chinese diets, accounting for up to 84% of energy and 70% of protein intake in Chinese women in 2000. However, from 1991 to 2009, plant-based food intake decreased 12.4%, a reduction of 66.2 g to 58.0 g per day (Cui and Dibley 2012). A possible explanation for the increasing proportion of energy from protein, especially in the high urbanicity group, despite declining intake of the major source of protein in Chinese diets is that urbanization increases access and affordability of animal-source foods, as well as promotes increased frequency of consuming food prepared outside the home (FPOH), of which animal source food is a key component (Du, Lu et al. 2002, Liu, Zhai et al. 2006). Indeed, per capita annual consumption of animal foods more than tripled from 11kg to 38 kg between 1952 and 1992 (Du, Lu et al. 2002). Further supporting the notion that urbanization plays an important role in the rise of animal-based protein consumption are studies that find urban areas to consume significantly more protein from animal-sourced foods, including meat, eggs, and milk, than their rural counterparts (Qu, Zhang et al. 2000, Du, Lu et al. 2002).

*Sodium-Potassium*

It is interesting to note the dramatic change in sodium consumption from 1991 to 2011 when there is only minor change in potassium consumption in this same timeframe. One possible reason for this difference is that Chinese people are generally unaware of the extreme lack of potassium in their normal diet (Epstein and Wang 2011). Sodium, on the other hand, is given much public and governmental attention in China— healthcare reforms in 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 $d^{-1}$ in rural communities to 9 g $d^{-1}$ across the country by 2015 (Hvistendahl 2014, Du, Neiman et al. 2014)). These efforts to decrease sodium intake appear successful given the significant decrease in sodium consumption observed across all sex and urbanicity groups in our study. In addition, the ownership of refrigeration has decreased intake of salted preserved fish and other dishes. However, despite these declines, sodium consumption levels among Chinese adolescents are still much higher than Institute of Medicine's recommendation of <2200 mg $d^{-1}$ and <2300 mg $d^{-1}$ for 9 – 13 and 14 – 18 year olds, respectively (Electrolytes and Water 2005). Potassium similarly continues to miss intake guidelines set by the Institute of Medicine; Chinese adolescents are obtaining less than half the recommended >4500 mg $d^{-1}$ and >4700 mg $d^{-1}$ for 9 – 13 and 14 – 18 year olds, respectively (Electrolytes and Water 2005). Driven primarily by decreasing sodium consumption, sodium-potassium ratios decreased across all sex and urbanicity groups from 1991 to 2011 but are still above recommended levels and require further reduction efforts in Chinese adolescents.

There is dramatic variation in sodium and sodium-potassium ratio trends between the low urbanicity group and the medium and high urbanicity groups. For both dietary measures, the medium and high urbanicity groups show very similar, U-shaped trends, but the low urbanicity group demonstrates nearly linear dietary trends with seemingly no relation to the other urbanicity groups. 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 urbanization differs greatly based on a region's baseline 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. For example, existing literature shows that there are differences in sodium intake and behaviors among urban and rural populations, such as the practice of salting vegetables for preservation in rural communities when refrigerators are not available or affordable (Tian, Hu et al. 1996, Du, Neiman et al. 2014). If urbanization at the low urbanicity level promotes widespread purchasing of newly affordable refrigerators, there may be a faster decline in sodium intake due to urbanization at the low urbanicity level than at the medium or high urbanicity level, where there is likely a higher prevalence of household refrigerators. However, there is a gap in the literature on factors, such as the prevalence of household refrigerators in different urban settings, that may contribute to differences in sodium intake between more rural and more urban areas, and 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 (Tian, Hu et al. 1996, Du, Neiman et al. 2014).

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 (Tian, Hu et al. 1996). 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; however, this is representative of the average education level among all adults aged 18 and older, not just parents with adolescent children (Jones-Smith and Popkin 2010). As such, we additionally included mother's education as an important covariate in our study to account for any possible effects of parent education on adolescent dietary intake, though many researchers find grandparents are playing a greater role than previously expected (Hsu, Tseng et al. 1985, Short, Zhai et al. 2001, Short 2004). 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 generally associated with decreased prevalence of hypertension; however, cases of pre-hypertension and hypertension have increased 8.13% in Chinese adolescents from 1991 to 2004 (Zhao, Qi et al. 2011, Du, Neiman et al. 2014, Liang, Xi et al. 2011). 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 (Tian, Hu et al. 1996, Du, Neiman et al. 2014). 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 similar dietary trends observed across the 9 provinces, the dietary intakes of the three megacities show striking similarities. The three megacities present energy compositions higher in carbohydrate, lower in fat, and higher in protein. The proportions of energy derived from each macronutrient are extrapolations of the macronutrient trends already observed in the 9 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 Food Composition Tables (FCT) (Yue-xin, Guangya et al. 2002). 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 table results assume identical composition for selected dishes in home and restaurant preparations, when in actuality, there is enormous variability in nutrient content of dishes and their food components (Popkin, Lu et al. 2002). One analysis currently underway 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. In the 2016 and future CHNS surveys, dishes will also be collected to understand the average components of current dishes consumed in China (Popkin, Lu et al. 2002). Additionally, because our study analyzes total consumption of each macronutrient, 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 in other studies in Chinese adolescents (Popkin, Lu et al. 2002, Du, Lu et al. 2002, Zhai, Du et al. 2014). 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 as snacks and food consumed away from home, as seen in the literature (Du, Lu et al. 2002, Liu, Zhai et al. 2006, Zhai, Du et al. 2014, Wang, Zhang et al. 2013). However, this is beyond the scope of this paper

Another limitation that significantly decreased our study population was missing information from the CHNS concerning mother's education. More specifically, 49.7% (n=1617) of our original sample was excluded from our analysis because this missing data. To test the impact of retaining mother's education as a covariate in exchange for diminished sample size, linear regression models were run excluding mother's education from adjusted covariates, and dietary means were compared (see appendix). We found that across all survey years by both sex and urbanicity, almost all proportions of energy from carbohydrate, fat, and protein as well as sodium-potassium ratios were within 10% of corresponding values calculated when adjusting for mother's education. The only exception was within the low urbanicity group's sodium-potassium ratio in 2011, a ratio of 1.6 with adjustment as compared to a ratio of 2.0 without adjustment of mother's education. Despite this discrepancy, there was no overall deviation from the observed trend of decreasing sodium-potassium ratios from 1991 to 2011 in the low urbanicity group when adjusting for mother's education. Because overall trends from 1991 to 2011 in all sex and urbanicity groups were the same with or without controlling for mother's education, we decided to include mother's education as a covariate in our analysis, because mother's education has been shown in to be an important predictor of children's dietary intake patterns (Wang, Bentley et al. 2002). Future studies might consider substituting the education of a surrogate, such as a grandmother or head of household, for mother's education if missing information continues to be a limiting factor in future data collection.

## 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. Despite successful efforts to decrease 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. 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.

Table 1: Characteristics of participants, China Health and Nutrition Survey 1991 – 2011

| | 1991 | 2000 | 2011 | 3 megacities |
|---|---|---|---|---|
| Sample (n) | 489 | 677 | 253 | 162 |
| Age (n) | | | | |
| 12 to 14 y | 181 (37.0%) | 319 (47.1%) | 107 (42.3%) | 91 (29.8%) |
| 14 to 17 y | 308 (63.0%) | 358 (52.9%) | 146 (57.7%) | 214 (70.2%) |
| Male (n, %) | 251 (51.3%) | 414 (61.2%) | 151 (59.7%) | 156 (51.2%) |
| Urbanicity Index (%) | | | | |
| Low | 313 (47.6%) | 125 (43.1%) | 51 (10.8%) | |
| Middle | 295 (44.8%) | 113 (39.0%) | 269 (57.1%) | |
| High | 50 (7.6%) | 52 (17.9%) | 151 (32.1%) | |
| Per Capita Income[1] | | | | |
| Overall (mean ± SD) | 2888 ± 1885 | 5393 ± 4514 | 14251 ± 16216 | 18839 ± 15372 |
| Low (mean ± SD) | 1934 ± 869 | 1959 ± 958 | 1710 ± 1147 | |
| Middle (mean ± SD) | 4451 ± 632 | 4596 ± 697 | 4797 ± 616 | |
| High (mean ± SD) | 7741 ± 1885 | 9463 ± 5058 | 17754 ± 17169 | |
| Mother's Education | | | | |
| Low | 381 (77.9%) | 266 (39.3%) | 73 (28.9%) | |
| Middle | 76 (15.5%) | 204 (30.1%) | 107 (42.3%) | |
| High | 32 (6.5%) | 207 (30.6%) | 73 (28.9%) | |
| Region | | | | |
| North | 106 (21.7%) | 282 (41.7%) | 81 (32.0%) | |
| Central | 194 (39.7%) | 186 (27.5%) | 75 (29.6%) | |
| South | 189 (38.7%) | 209 (30.9%) | 253 (38.3%) | |
| Family Size | | | | |
| 2 to 3 | 137 (28.0%) | 388 (57.3%) | 151 (60.0%) | |
| 4+ | 352 (72.0%) | 289 (42.6%) | 102 (40.0%) | |

[1] values are means and standard deviations measure in renminbi

Table 2: macronutrient composition of dietary energy and micronutrients, unadjusted

| | 1991 | 2000 | 2011 | Three mega cities |
|---|---|---|---|---|
| Macronutrient Distribution | | | | |
| % energy from fat | 22.1 | 28.4 | 31.7 | 37 |
| % energy from carbohydrates | 66.4 | 59.3 | 54.8 | 46.3 |
| % energy from protein | 11.5 | 12.2 | 13.5 | 16.5 |
| Sodium | | | | |
| Sodium g/d | 7.9 | 6.0 | 4.4 | 4.6 |
| Potassium g/d | 1.7 | 1.5 | 1.7 | 1.7 |
| Sodium/potassium ratio | 5.0 | 4.2 | 2.9 | 3.0 |

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

| | | 1991 | | 2000 | | 2011 | |
|---|---|---|---|---|---|---|---|
| | | Mean | *SE* | Mean | *SE* | Mean | *SE* |
| **Sodium** | | | | | | | |
| All** | | 7879.0 | *285.4* | 6003.1 | *225.4* | 4361.9 | *398.9* |
| Sex | | | | | | | |
| | Male** | 7927.2 | *376.1* | 6070.5 | *270.9* | 4417.3 | *508.9* |
| | Female** | 7750.5 | *437.1* | 5945.8 | *391.9* | 4335.5 | *659.1* |
| Urbanicity | | | | | | | |
| | Low** | 8575.9 | *423.8* | 5448.9 | *419.7* | 3047.5 | *1151.4* |
| | Medium** | 7297.7 | *473.1* | 6464.0 | *475.4* | 4623.5 | *770.3* |
| | High** | 5837.6 | *561.4* | 6393.8 | *242.8* | 4475.3 | *333.4* |
| **Potassium** | | | | | | | |
| All | | 1715.2 | *35.3* | 1551.0 | *27.9* | 1697.8 | *49.3* |
| Sex | | | | | | | |
| | Male | 1763.3 | *47.4* | 1613.2 | *34.1* | 1765.3 | *64.1* |
| | Female | 1651.2 | *53.1* | 1469.4 | *47.6* | 1586.6 | *80.1* |
| Urbanicity | | | | | | | |
| | Low* | 1739.4 | *45.6* | 1597.7 | *45.1* | 1545.8 | *123.8* |
| | Medium* | 1668.0 | *59.0* | 1392.4 | *59.2* | 1420.0 | *96.0* |
| | High** | 1539.5 | *99.9* | 1581.0 | *43.2* | 1866.0 | *59.3* |
| **Sodium–Potassium Ratio** | | | | | | | |
| All** | | 5.0 | *0.2* | 4.2 | *0.2* | 2.9 | *0.3* |
| Sex | | | | | | | |
| | Male** | 4.7 | *0.2* | 4.1 | *0.2* | 2.7 | *0.3* |
| | Female** | 5.3 | *0.4* | 4.4 | *0.3* | 3.3 | *0.6* |
| Urbanicity | | | | | | | |
| | Low** | 5.6 | *0.3* | 3.8 | *0.3* | 1.6 | *0.8* |
| | Medium** | 4.6 | *0.3* | 5.1 | *0.3* | 3.3 | *0.5* |
| | High** | 3.9 | *0.4* | 4.2 | *0.2* | 2.8 | *0.2* |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Dietary Energy (kcal)** | | | | | | | |
| All** | | 2523.7 | *31.5* | 2118.5 | *24.9* | 1856.7 | *44.1* |
| Sex | | | | | | | |
| | Male** | 2619.1 | *45.5* | 2228.3 | *32.8* | 2019.6 | *61.6* |
| | Female** | 2382.7 | *43.3* | 1968.1 | *38.8* | 1651.9 | *65.2* |
| Urbanicity | | | | | | | |
| | Low** | 2562.7 | *40.7* | 2091.4 | *40.3* | 1788.3 | *94.2* |
| | Medium** | 2407.0 | *57.8* | 2059.7 | *58.1* | 1766.5 | *94.2* |
| | High** | 2326.3 | *83.4* | 2185.6 | *36.1* | 1970.6 | *49.5* |
| **Carbohydrate Energy (%)** | | | | | | | |
| All** | | 63.3 | *0.5* | 59.9 | *0.4* | 59.2 | *0.7* |
| Sex | | | | | | | |
| | Male** | 63.1 | *0.7* | 61.2 | *0.5* | 59.7 | *1.0* |
| | Female** | 63.2 | *0.7* | 58.2 | *0.7* | 58.2 | *1.1* |
| Urbanicity | | | | | | | |
| | Low** | 68.4 | *0.6* | 64.9 | *0.6* | 66.7 | *1.7* |
| | Medium** | 60.2 | *0.9* | 59.5 | *0.9* | 56.8 | *1.5* |
| | High* | 57.1 | *1.5* | 53.7 | *0.6* | 53.2 | *0.9* |
| **Fat Energy (%)** | | | | | | | |
| All** | | 24.7 | *0.5* | 28.0 | *0.4* | 27.9 | *0.7* |
| Sex | | | | | | | |
| | Male** | 24.7 | *0.7* | 26.7 | *0.5* | 27.3 | *1.0* |
| | Female** | 24.8 | *0.7* | 29.7 | *0.7* | 29.1 | *1.1* |
| Urbanicity | | | | | | | |
| | Low** | 20.3 | *0.6* | 23.7 | *0.6* | 21.2 | *1.7* |
| | Medium* | 27.3 | *0.9* | 28.8 | *1.0* | 30.8 | *1.5* |
| | High | 30.2 | *1.5* | 33.1 | *0.6* | 32.8 | *0.9* |
| **Protein Energy (%)** | | | | | | | |
| All** | | 12.0 | *0.1* | 12.1 | *0.1* | 12.9 | *0.2* |
| Sex | | | | | | | |
| | Male** | 12.0 | *0.2* | 12.1 | *0.1* | 12.9 | *0.2* |
| | Female** | 12.0 | *0.2* | 12.1 | *0.2* | 12.7 | *0.3* |
| Urbanicity | | | | | | | |
| | Low** | 11.2 | *0.1* | 11.4 | *0.1* | 12.1 | *0.4* |
| | Medium | 12.5 | *0.2* | 11.7 | *0.2* | 12.4 | *0.4* |
| | High** | 12.7 | *0.4* | 13.2 | *0.2* | 14.0 | *0.2* |

Multivariable regression models were used to adjust results for age, sex, urbanicity, per capita income, mother's education, region, and family size. Significant trends across the survey years: *p<0.05, **p<0.01 with the use of Bonferroni adjustment; test for trend

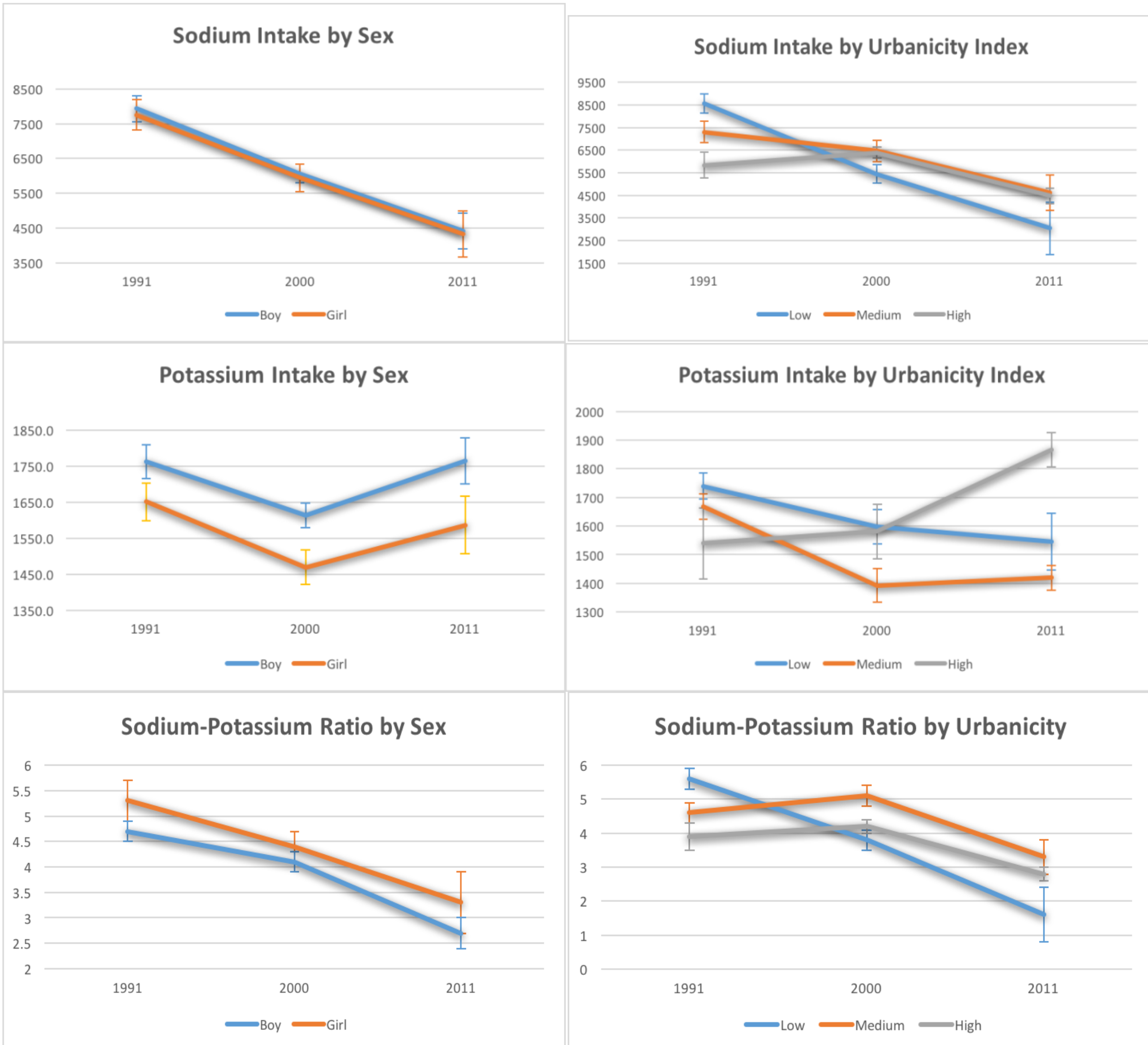


Figure 1: Sodium and Potassium Intakes and Sodium–Potassium Ratios by Sex and Urbanicity Index from 1991 to 2011. Proportions were adjusted for age, sex, urbanicity, per capita income, mother's education, region, and family size.


Figure 2: Proportions of energy from protein, carbohydrate, and fat in Chinese adolescents from 1991 to 2011. Proportions were adjusted for age, sex, urbanicity, per capita income, mother's education, region, and family size. Labeled proportions without a common letter differ among years ($P<0.05$).

Appendix

Supplementary Table 1: Trends in Dietary Energy, Macronutrient, and Sodium–Potassium Ratio by sex and urbanicity without adjustment for mother's education

| | | 1991 | | 2000 | | 2011 | |
|---|---|---|---|---|---|---|---|
| | | Mean | *SE* | Mean | *SE* | Mean | *SE* |
| **Sodium–Potassium Ratio** | | | | | | | |
| All | | 5.0 | *0.1* | 4.2 | *0.1* | 2.9 | *0.2* |
| Sex | | | | | | | |
| | Male | 4.8 | *0.1* | 4.0 | *0.1* | 2.6 | *0.2* |
| | Female | 5.1 | *0.3* | 4.5 | *0.2* | 3.4 | *0.4* |
| Urbanicity | | | | | | | |
| | Low | 5.5 | *0.2* | 3.8 | *0.2* | 2.0* | *0.6* |
| | Medium | 4.6 | *0.2* | 5.1 | *0.2* | 3.3 | *0.3* |
| | High | 3.9 | *0.3* | 4.3 | *0.1* | 2.8 | *0.2* |
| **Dietary Energy (kcal)** | | | | | | | |
| All | | 2538.2 | 21.7 | 2109.6 | 17.1 | 1862.4 | 31.2 |
| Sex | | | | | | | |
| | Male | 2634.6 | *31.1* | 2221.9 | *22.3* | 2005.2 | *42.7* |
| | Female | 2393.6 | *30.0* | 1955.6 | *26.8* | 1660.5 | *46.6* |
| Urbanicity | | | | | | | |
| | Low | 2574.9 | *28.0* | 2084.2 | *27.3* | 1786.3 | *76.9* |
| | Medium | 2415.6 | *39.6* | 2059.7 | *39.8* | 1795.2 | *65.2* |
| | High | 2348.9 | *57.8* | 2180.0 | *25.0* | 1947.2 | *35.2* |
| **Carbohydrate Energy (%)** | | | | | | | |
| All | | 64.0 | 0.4 | 59.8 | 0.3 | 58.6 | 0.5 |
| Sex | | | | | | | |
| | Male | 64.2 | *0.5* | 61.0 | *0.4* | 59.0 | *0.7* |
| | Female | 63.6 | *0.5* | 58.2 | *0.5* | 57.7 | *0.8* |
| Urbanicity | | | | | | | |
| | Low | 69.4 | *0.4* | 64.3 | *0.4* | 64.8 | *1.2* |
| | Medium | 60.4 | *0.6* | 59.2 | *0.6* | 57.0 | *1.0* |
| | High | 56.5 | *1.0* | 54.1 | *0.4* | 52.9 | *0.6* |
| **Fat Energy (%)** | | | | | | | |
| All | | 24.0 | 0.4 | 28.1 | 0.3 | 28.5 | 0.5 |
| Sex | | | | | | | |
| | Male | 23.8 | *0.5* | 26.9 | *0.4* | 28.2 | *0.7* |
| | Female | 24.4 | *0.5* | 29.7 | *0.5* | 29.5 | *0.1* |
| Urbanicity | | | | | | | |
| | Low | 19.3 | *0.4* | 24.3 | *0.4* | 23.2 | *1.2* |
| | Medium | 27.1 | *0.7* | 29.0 | *0.7* | 30.9 | *1.1* |
| | High | 30.9 | *1.0* | 32.8 | *0.4* | 33.0 | *0.6* |
| **Protein Energy (%)** | | | | | | | |
| All | | 11.9 | 0.1 | 12.1 | 0.1 | 12.9 | 0.1 |
| Sex | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Male | 12.0 | *0.1* | 12.1 | *0.1* | 12.8 | *0.2* |
| | Female | 12.0 | *0.1* | 12.1 | *0.1* | 12.7 | *0.2* |
| Urbanicity | | | | | | | |
| | Low | 11.2 | *0.1* | 11.4 | *0.1* | 12.0 | *0.3* |
| | Medium | 12.5 | *0.2* | 11.8 | *0.2* | 12.1 | *0.3* |
| | High | 12.6 | *0.3* | 13.1 | *0.1* | 14.0 | *0.2* |

Multivariable regression models were used to adjust results for age, sex, urbanicity, per capita income, region, and family size.
*Values that are not within 10% of corresponding values when adjusting for mother's education

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