

Is a Hypertension Diagnosis Associated With Improved Dietary Outcomes Within 2 to 4 Years? A Fixed-Effects Analysis From the China Health and Nutrition Survey

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Background—Evidence shows that dietary factors play an important role in blood pressure. However, there is no clear understanding of whether hypertension diagnosis is associated with dietary modifications. The aim of this study is to estimate the longitudinal association between hypertension diagnosis and subsequent changes (within 2–4 years) in dietary sodium, potassium, and sodium-potassium (Na/K) ratio.

Methods and Results—We included adults (18–75 years, $n=16\,264$) from up to 9 waves (1991–2015) of the China Health and Nutrition Survey. Diet data were collected using three 24-hour dietary recalls and a household food inventory. We used fixed-effects models to estimate the association between newly self-reported diagnosed hypertension and subsequent within-individual changes in sodium, potassium, and Na/K ratio. We also examined changes among couples and at the household level. Results suggest that on average, men who were diagnosed with hypertension decreased their sodium intake by 251 mg/d and their Na/K ratio by 0.19 within 2 to 4 years after diagnosis ($P<0.005$). Among spouse pairs, sodium intake and Na/K ratio of women decreased when their husbands were diagnosed ($P<0.05$). Household average sodium density and Na/K ratio decreased, and household average potassium density increased after a man was diagnosed. In contrast, changes were not statistically significant when women were diagnosed.

Conclusions—Our findings suggest that hypertension diagnosis for a man may result in modest dietary improvements for him, his wife, and other household members. Yet, diagnosis for a woman does not seem to result in dietary changes for her or her household members. (*J Am Heart Assoc.* 2019;8:e012703. DOI: 10.1161/JAHA.119.012703.)

Key Words: dietary changes • fixed-effects models • hypertension diagnosis • sodium intake

Cardiovascular diseases (CVDs) are the number 1 cause of global mortality, with 80% of CVD deaths occurring in low- and middle-income countries.^{1,2} Hypertension is the leading modifiable risk factor for CVD and for overall mortality and morbidity.³ In 2010, hypertension affected 1.4 billion

people, which represented 31% of all adults worldwide, disproportionately affecting lower and middle-income countries.⁴ In China in 2015, 244.5 million adults (23%) had hypertension, and another 435 million (41.3%) had prehypertension.⁵ Of those with hypertension, only 47% were diagnosed and 15% had controlled hypertension.⁵

Evidence from randomized controlled trial studies suggests that dietary factors play an important role in blood pressure reduction. For example, there is strong evidence of a linear, dose–response relationship between sodium reduction and blood pressure, with a greater effect among hypertensive individuals than among normotensive ones.^{6–9} In addition, evidence from observational studies suggests that sodium reduction prevents cardiovascular events^{10,11} and reduces mortality risk.¹² This response to sodium is modified by other dietary components. Low potassium intake potentiates the effect of high sodium intake on blood pressure, while high potassium intake attenuates it.^{13,14} Thus, reducing sodium and increasing potassium intake after hypertension diagnosis could offer significant benefits by reducing morbidity and mortality.

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Clinical Perspective

What Is New?

- Our study is among the first to explore changes in dietary intake of sodium, potassium, and their ratio associated with hypertension diagnosis using a prospective population-based design.
- We used comparable and validated sodium and potassium intake collected between 1991 and 2015, which allowed us to use appropriate statistical methods to control for unobserved individual heterogeneity and to have unambiguous temporal sequence.
- We additionally examined dietary changes among couples and at the household level associated with newly diagnosed hypertension, and this study provided evidence of modest changes in sodium intake and Na/K ratio when men were newly diagnosed.

What Are the Clinical Implications?

- Our findings suggest that a hypertension diagnosis conveys information that could help towards modestly improving dietary behaviors among Chinese men, and could be related to what the behavioral literature has termed as a “teachable moment.”
- We also found evidence of how diagnosis in a household member might reduce sodium intake of the other household members, highlighting the clustering of behaviors in the household.
- Efforts to increase hypertension diagnosis in China should continue given the observed benefits of diagnosis.

However, to our knowledge, evidence of the association between hypertension diagnosis and dietary modifications to reduce blood pressure after diagnosis is limited. Previous studies on dietary behavior change have focused on cross-sectional comparisons between groups^{15,16} or self-reported intention to reduce sodium intake among hypertensive adults.^{17–20} Cross-sectional associations may reflect confounding by unmeasured characteristics. One source of unmeasured confounding comes from permanent characteristics of individuals that may be associated with both diagnosis and dietary intake, such as health awareness, personality traits, and utilization of health services. For example, a health-conscious individual could be more likely to be aware of his/her hypertension status and more likely to engage in healthy behaviors, such as consuming low-sodium diets. This confounding by health consciousness would induce a spurious association between awareness of hypertension and diet. An additional limitation of cross-sectional studies is that they are unable to account for temporality. For instance, cross-sectional data may show that hypertensive and nonhypertensive individuals have similar sodium intake at a given

point in time, but would fail to capture trends in past sodium consumption that could have led to their current hypertension status. In this case, the resulting null association between hypertension diagnosis and sodium intake would be misleading if hypertensive individuals consumed much higher amounts of sodium before diagnosis but changed their behavior after diagnosis. Moreover, studies that use self-reported intention to reduce sodium intake are limited because these intentions might not translate into actual reduction.^{20,21} Voluntary reduction may be especially difficult in Western countries, where the major source of sodium is processed food,²² in contrast to non-Western countries such as China where the primary source of sodium is added salt.^{14,23,24} Since the sodium in processed foods is added during the manufacturing process and cannot be removed by consumers (as opposed to table salt added by the consumer), personal efforts to reduce sodium intake on a typical Western diet might not be effective.^{22,25,26}

The China Health and Nutrition Survey (CHNS) provides a unique opportunity to study the association between hypertension diagnosis and dietary changes for 3 primary reasons. First, the CHNS consists of 9 waves of longitudinal data with comparable in-depth dietary measurements throughout the study, which allow us to control for unobserved individual heterogeneity by using fixed-effects models and unambiguous temporal sequence. Second, the major sources of sodium in the Chinese diet are salt and soy sauce added during food preparation, as opposed to Western countries.^{14,23,24} Thus, it is possible that individual intention to reduce sodium intake may more readily translate to sodium reduction in the Chinese context. Third, sodium intake is a serious concern in China, where estimations from 2009 showed that mean sodium intake was 4.7 g/d,¹⁴ which is considerably higher than the World Health Organization recommended <2 g/d, and the Institute of Medicine’s recommended <2.3 g/d,^{27,28} and higher than most other countries.²⁴ Mean potassium intake was 1.8 g/d,¹⁴ also far below the intakes recommended by the World Health Organization (>3.5 g/d) and the Institute of Medicine (>4.7 g/d).^{28,29} Additionally, according to a recent analysis from the Global Burden of Disease, China had the highest age-standardized rate of diet-related CVD deaths among 195 countries, with high intake of sodium being the leading dietary risk factor for deaths and disability-adjusted life-years.³⁰

Given that hypertension is an urgent public health concern and that dietary factors are known to affect blood pressure, there is an important need to understand whether hypertension diagnosis leads to dietary changes, such as reductions in sodium intake. Therefore, the aim of this study is to use population-based data to estimate the longitudinal association between newly self-reported physician diagnosis of hypertension and changes in sodium intake, potassium intake, and the

sodium-potassium (Na/K) ratio within 2 to 4 years. Given important differences in biology and health behaviors between Chinese men and women, we also tested for sex heterogeneity in this association.^{5,14,31}

Methods

The data and analytic methods are available to other researchers upon reasonable request. The CHNS data can be accessed at the CHNS website (<https://www.cpc.unc.edu/projects/china>).

The CHNS

The CHNS is an ongoing household-based longitudinal cohort study started in 1989, and followed by 9 additional waves collected in 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015. A stratified multistage, cluster process was used to select the samples surveyed in each of the provinces included in the study. Two cities (the provincial capital and a lower-income city) and 4 counties (stratified by income) were selected from each province. Within cities, 2 urban and 2 suburban communities were selected; within counties, 1 community in the capital city and 3 rural villages were chosen. Twenty households per community were then selected for participation, and all household members were surveyed. The survey started with 8 provinces (Liaoning, Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi, and Guizhou). In 1997, a ninth province was included (Heilongjiang); in 2011, 3 mega-cities joined the cohort (Beijing, Chongqing, and Shanghai), and in 2015, 3 more provinces were included (Shaanxi, Yunnan, and Zhejiang) using a similar sampling methodology for a total of 15 provinces and 3 cities. Each survey round collected community, household, and individual data. Participants signed informed consent before participating in the survey. The study was approved by the Institutional Review Boards of the University of North Carolina at Chapel Hill, and the Institute of Nutrition and Health, China Center for Disease Control and Prevention. More detailed survey procedures are described elsewhere.³²

Dietary Assessment

Dietary intake was assessed with a combination of 3 consecutive 24-hour dietary recalls, and a household inventory collected during the same 3-day period. The 3 days of dietary data were randomly allocated from Monday to Sunday. At each survey wave, trained nutritionists visited study participants at their home. In the 24-hour dietary recalls, a detailed description of food consumption was reported and recorded for each individual, including time, type, amounts,

and place of foods consumed. Foods consumed out of home were also recorded. For the household inventory, condiments and oils were weighed on a daily basis. Household consumption was estimated as the total consumption of condiments and oils, minus wastages. Condiments and oil consumption from the household inventory was then allocated to each individual at the household based on the amount of the specific food consumed as reported in the 3-day 24-hour recalls.^{33–35} Therefore, for each of the 3 days of dietary data, daily intake was estimated with a 24-hour dietary recall, plus condiments and oils from the household inventory of that day. Chinese food composition tables were used to obtain energy and nutrient values. Salt, soy sauce, and monosodium glutamate were among the condiments weighed in the household inventory. A validation study evaluated the accuracy of sodium and potassium intakes at the individual level (estimated from the three 24-hour dietary recalls plus the household inventory data) using urinary sodium and potassium excretions from 24-hour urine samples collected during the same 3 consecutive days. The correlation coefficients were 0.58 between dietary intake (from the combination of the 24-hour recalls and the household inventory) and urinary excretion of sodium, and 0.59 between dietary intake and urinary excretion of potassium ($P<0.005$).¹⁴ We estimated individual daily energy intake (kcal/d), sodium intake (mg/d), potassium intake (mg/d), and Na/K ratio as an average of the 3 days of collected dietary intake.

Newly Diagnosed Hypertension

Diagnosed hypertension was defined as self-reported physician diagnosis of hypertension with the question “Has a doctor ever told you that you suffer from high blood pressure?” from the disease history section of the individual questionnaire. A first-time self-reported hypertension diagnosis could occur at any wave between 1993 and 2015. Hereafter, we refer to the first time a hypertension diagnosis was self-reported as “newly diagnosed hypertension.”

Covariates

Age, sex, pregnancy status, marital status, and health insurance availability were self-reported at each survey. Household income was derived from individual and household questionnaires at each survey, and inflated to 2015-Yuan currency for comparability over time. We also used the validated urbanization index from the CHNS, which reflects the degree of urbanization in each community at each time point. It comprises 12 components, constructed using detailed information on the community infrastructure, services, and demographic and economic environment, and has a

possible range of 0 to 120, with a higher score reflecting more urban characteristics.³⁶

Additional Variables

Weight and height were measured by trained interviewers at each survey with subjects without shoes and in light clothing. Weight was recorded to the nearest 0.1 kg on a calibrated floor scale (Seca Zhong Guo, Hangzhou, China), and height to the nearest 0.2 cm using a portable SECA stadiometer. Body mass index (BMI) was calculated as kg/m², and overweight classified with the World Health Organization (BMI ≥25 kg/m²), and the Chinese (BMI ≥24 kg/m²) cut-off points.^{37,38} Systolic and diastolic blood pressure were measured on the right arm in triplicate at each survey wave, using sphygmomanometers (measuring range: 0–300 mm Hg) with appropriate cuff sizes according to standardized protocol.³⁹ The average of the 3 measurements was estimated, and used to define undiagnosed hypertension as systolic/diastolic blood pressure ≥140/90 mm Hg without doctor diagnosis of hypertension. We did not adjust for these variables in our main models but used them in descriptive analyses and for sensitivity analysis.

Sample

The eligible sample included 16 785 adults without self-reported hypertension at their first entry wave, aged 18 to 75 years with complete dietary data, a yes/no answer to self-reported physician diagnosis of hypertension, and at least 2 survey visits between 1991 and 2015 (71 874 observations). We excluded observations of pregnant women at the time of the survey, implausible values of sodium intake (defined as sodium intake <500 mg/d), implausible values of energy intake (defined as energy intake <500 or >4500 kcal/d), and with missing values for urbanization index, health insurance, or household income. Subjects with <2 survey visits after exclusion of observations because of pregnancy (n=88), implausible values of sodium or energy intake (n=268), and missing covariates (n=165) were excluded. Thus, our final analytical sample comprised 16 264 adults (68 300 observations).

Statistical Analysis

In descriptive analyses, we present characteristics of our study sample at first entry to the CHNS stratified by sex, and compare characteristics between men and women using the *t* test for continuous variables and χ^2 test for categorical variables.

We used fixed-effects models to assess whether within-individual change in self-reported hypertension diagnosis

status was associated with within-individual changes in sodium intake, potassium intake, and Na/K ratio. Fixed-effects models have the advantage of controlling for potential time-invariant confounders that vary across individuals (eg, health awareness). Moreover, fixed-effects models use each individual as his or her own control, by comparing an individual's outcome before the event, with that same individual's outcome after the event, in this case, dietary intake before and after hypertension diagnosis.^{40,41}

The following was the general specification of our model:

$$Y_{it} = \beta_1 D_{1it} + \beta_2 D_{2it} + \gamma Z_{it} + \delta \text{Wave}_t + \alpha_i + \epsilon_{it}, \quad (1)$$

where Y_{it} represents dietary intake (sodium intake, potassium intake, and Na/K ratio) for individual *i* at time *t*, D_{1it} was an indicator variable that took a value of 1 at the wave that individual *i* was newly diagnosed with hypertension, and zero otherwise, considering that a first-time hypertension diagnosis could occur at any wave between 1993 and 2015. D_{2it} was an indicator variable that took a value of 1 at subsequent waves after the first-time hypertension diagnosis. In other words, if an individual reported a first-time hypertension diagnosis in 1997, D_{1it} would take the value of 1 at the 1997 wave, and zero at all other waves, and D_{2it} would take the value of 1 starting 2000 onwards, and zero at 1997 and before. Z_{it} were time-variant covariates, Wave_t were the wave indicator variables and thus, controlled for secular changes through time, α_i were individual's fixed effects and controlled for individual *i*'s measured and unmeasured time-invariant characteristics, and ϵ_{it} was the error term. Therefore, β_1 was the main coefficient of interest since it captured the association between newly diagnosed hypertension and change in the 3 dietary intake outcomes studied (sodium, potassium, and Na/K). In other words, β_1 represented the average change in sodium, potassium, and Na/K ratio before and after hypertension diagnosis (ie, intake from waves without diagnosis versus intake at the first time hypertension was reported). Since survey waves were collected 2 (eg, 1991–1993) to 4 (eg, 2000–2004) years apart, the coefficient represents change within 2 to 4 years associated with newly diagnosed hypertension. Diagnosis could have occurred any time within that period. Given that the main interest of this analysis is the change associated with newly diagnosed hypertension, we are controlling for changes from the second visit postdiagnosis onward without any further interpretation (β_2). The time-variant covariates included were age (log-transformed), energy intake (kcal/d), per capita household income, urbanization index, and health insurance (yes/no). We adjusted by energy intake to control for confounding caused by differences in energy intake, to remove extraneous variation (high correlation between absolute micronutrient intake and energy intake), and to reduce measurement error.

We assessed whether the association of newly diagnosed hypertension and dietary intake outcomes differed between men and women by testing the interaction of sex with newly diagnosed hypertension (D_{iit}) in a fully interacted model. Given that heterogeneity was found by sex (interaction $P<0.05$) in the 3 models (sodium intake, potassium intake, and Na/K), we stratified all analyses for ease of interpretation.

As mentioned previously, fixed-effects model estimations are based on within-individual variability in the exposure and outcomes, which removes within-individual correlation caused by personal time-invariant characteristics. However, excluding between-individual variation leads to decreased efficiency. Thus, we compared fixed-effects models consistency versus efficiency trade-off against random-effects and pooled ordinary least-squares regression models using the Hausman specification test,⁴² where the null hypothesis is that estimated coefficients under the random-effects or pooled ordinary least-squares models are consistent.

Taking advantage of the household survey design of the CHNS and to further understand the heterogeneity in the association by sex, we explored changes across spouses in our selected outcomes depending on the timing of diagnosis within the couple, and diet changes of the spouse when his/her spouse was diagnosed. We restricted these analyses to the head of household and his/her spouse ($n=10\ 572$). For men and women, we estimated fixed-effects models under the following scenarios: (1) change in diet outcomes if diagnosed before spouse, (2) change in diet outcomes if diagnosed after spouse, (3) change in diet outcomes if diagnosed at the same time as spouse, and (4) spouse's change when his/her spouse is diagnosed. For example, if within a couple, the wife was newly diagnosed, she could only be in 1 of the first 3 scenarios and would be excluded from the other 2. All couples were included in the fourth scenario, regardless of timing of diagnosis. Since the CHNS includes all members of the household, and the head of household could change between waves (eg, son of the head of household became the head of household in a following wave), 3.6% of households had >2 members during the whole observation period in this restricted sample.

Furthermore, in order to assess changes at the household level when a family member was newly diagnosed, we estimated household average sodium density, average potassium density, and average Na/K at each survey wave, and used them as outcomes in fixed-effects models with robust standard errors to account for nonindependent clustering. Sodium and potassium densities were estimated as mg per 100 kcal. Models were adjusted by the same time-variant covariates (age, energy intake, per capita household income, urbanization index, and health insurance). All analyses were

conducted using Stata 14.2 (StataCorp LLC, College Station, TX).

Sensitivity Analyses

To determine whether estimates from our main analysis were robust to other possible time-variant confounders, we further adjusted by BMI (as a continuous variable) and marital status (as a categorical variable). There were 3570 missing observations for BMI, and 485 missing observations for marital status. Therefore, we assessed whether the differences in the estimates were because of confounding or to selection bias by restricting the model to the sample with complete data, but without adjusting by the tested variable (BMI or marital status). We also performed the following sensitivity analyses: (1) excluding observations with >4 years between waves (ie, when individuals skipped waves during the survey follow-up), (2) excluding individuals from the mega-cities included in 2011, considering the possible heterogeneity in the association between mega-cities and the other 9 regions, but with reduced sample sizes needed to estimate stratified models, and (3) restricting to newly diagnosed and undiagnosed individuals, thus leaving observations of undiagnosed hypertensive adults ($\geq 140/90$ mm Hg without hypertension diagnosis) to account for secular trends, plus all observations of individuals who changed hypertension diagnosis status (ie, pre- and postdiagnosis observations of newly diagnosed individuals, regardless of whether the prediagnosis observations were normotensive).

Results

Absolute sodium and potassium intake at first entry were higher for men relative to women (5620 versus 5320 mg of sodium, and 1770 versus 1590 mg of potassium, $P<0.001$), while Na/K was higher for women compared with men (3.68 versus 3.48, $P<0.001$) (Table 1). Of the 16 264 individuals in our study sample, 2333 individuals changed from not having a hypertension diagnosis to having a hypertension diagnosis (1156 men and 1177 women). Over time, sodium intake, potassium intake, and the Na/K ratio decreased in men and women (Figure and Table S1).

To assess appropriate model specification, we used the Hausman test to determine whether to use random- or fixed-effects models. The null hypotheses for the Hausman specification tests were rejected for all models ($P<0.001$), suggesting that fixed-effects models were the appropriate specification (Table 2). On average, men who were newly diagnosed with hypertension decreased their sodium intake by 251 mg/d ($P=0.005$), and their Na/K ratio by 0.20 ($P=0.005$) within 2 to 4 years after diagnosis (each estimate

Table 1. Characteristics of Study Sample at First Entry by Sex, China Health and Nutrition Survey 1991–2015

	Men (n=7924)	Women (n=8340)	P Value*	Number of Participants
Age, y	39.3 (14.2)	39.5 (13.6)	0.2	16 264
Dietary intake [†]				16 264
Energy, kcal/d	2480 (684)	2140 (630)	<0.001	
Sodium, mg/d	5620 (2950)	5320 (2840)	<0.001	
Potassium, mg/d	1773 (722)	1590 (698)	<0.001	
Na/K	3.48 (2.17)	3.68 (2.27)	<0.001	
Urbanization index [‡]	56.7 (21.6)	57.7 (21.8)	0.003	16 264
Per capita household income, 1000 Yuan [§]	7.2 (9.9)	7.2 (10.2)	0.7	16 264
Proportion with health insurance	43.0	40.1	<0.001	16 264
Mega-cities	9.4	10.3	0.06	16 264
Wave at entry			<0.001	16 264
1991	36.0	37.7		
1993	8.7	6.8		
1997	17.2	14.6		
2000	7.6	7.6		
2004	8.0	8.6		
2006	3.9	3.6		
2009	6.6	7.3		
2011	12.0	13.7		
Number of survey visits			<0.001	16 264
2	33.3	35.3		
3	15.4	14.2		
4	12.1	10.8		
5	11.1	9.1		
6	10.4	9.8		
7	8.8	8.6		
8	5.7	6.8		
9	3.4	5.3		
Average number of visits	4.16 (2.13)	4.24 (2.28)	0.02	16 264
Additional characteristics				
Marital status			<0.001	16 163
Never married	21.1	9.8		
Married	76.7	85		
Divorced/separated	0.9	1		
Widowed	1.3	4.1		
Undiagnosed hypertension	14.3	8.7	<0.001	15 653
SBP, mm Hg	117.8 (14.4)	112.9 (15.4)	<0.001	15 654
DBP, mm Hg	76.9 (9.9)	73.6 (10.0)	<0.001	15 653
BMI, kg/m ²	22.2 (3.0)	22.4 (3.2)	<0.001	15 555

Continued

Table 1. Continued

	Men (n=7924)	Women (n=8340)	P Value*	Number of Participants
Overweight, WHO [†]	17	18.9	0.003	15 555
Overweight, China [#]	24.5	27.4	<0.001	15 555

Values are means (SD) or percentages. BMI indicates body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure; WHO, World Health Organization.

**t* test and χ^2 test were used to compare the continuous and categorical variables, respectively, between men and women.

[†]Dietary intake derived from 3-day 24-hour recalls and simultaneous weighed household inventory at each time point.

[‡]Urbanization defined by a multicomponent urbanicity scale with possible score of 0 to 120 points.

[§]Per capita household income inflated to 2015 Yuan values.

^{||}Undiagnosed hypertension defined as SBP/DBP \geq 140/90 mm Hg without physician diagnosis of hypertension.

[¶]Classified using the WHO cut-off point of BMI \geq 25 kg/m².

[#]Classified using the Chinese cut-off point of BMI \geq 24 kg/m².

comes from a separate model; Table 3). For women, changes in sodium intake, potassium intake, and Na/K ratio after they reported a hypertension diagnosis were nonsignificant.

Similar coefficients were obtained when we estimated changes with different diagnosis timing within couples (Table 3). On average, men who were diagnosed before their wives decreased their sodium intake by 227 mg/d ($P=0.04$). Changes for men diagnosed after their wives, and at the same wave as their wives were similar in direction and magnitude but not statistically significant, probably because of the small number of individuals who changed diagnosis status in those

groups (92 men diagnosed after their wives, and 68 at the same wave). When men were newly diagnosed, their wives' sodium intake and Na/K ratio decreased (-229 mg/d, $P=0.02$ and -0.20 , $P=0.01$). When women were newly diagnosed, regardless of diagnosis timing of their spouses, none of the estimates were statistically significant. Similarly, when women were newly diagnosed, their husbands' intake of sodium, potassium, and Na/K did not change significantly.

Household sodium density decreased by 8.3 mg/100 kcal ($P=0.04$), and potassium density increased by 1.6 mg/100 kcal ($P=0.04$) when a man was newly diagnosed in the

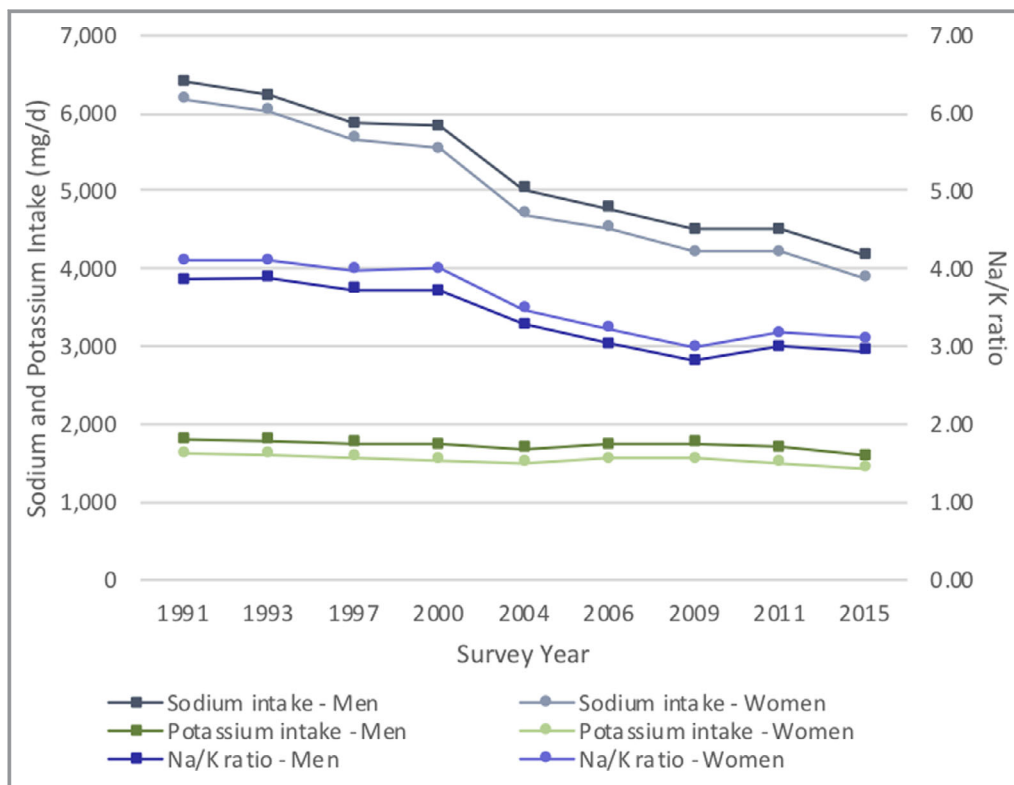


Figure. Descriptive means of sodium intake (mg/d), potassium intake (mg/d), and Na/K ratio by sex and wave, China Health and Nutrition Survey 1991–2015. N men person-observations=32 957; N women person-observations=35 343.

Table 2. Change in Sodium, Potassium, and Sodium-Potassium Ratio Within 2 to 4 Years Associated With Newly Diagnosed Hypertension, Estimated Using Ordinary Least-Squares, Random Effects, and Fixed-Effects Regression: China Health and Nutrition Survey 1991–2015*

	Sodium (mg/d)			Potassium (mg/d)			Sodium-Potassium Ratio			N (Person-Observations)			
	β	95% CI	P Value	Tests	β	95% CI	P Value	Tests	β		95% CI	P Value	Tests
Men													
Pooled OLS [†]	28.7	-115, 172	0.7	<0.001 [‡]	42.3	3.7, 81.0	0.03	<0.001	-0.05	-0.16, 0.07	0.4	<0.001	32 957
Random effects [§]	-10.6	-160, 140	0.9	<0.001	39.8	4.7, 48.2	0.03	<0.001	-0.06	-0.18, 0.06	0.3	<0.001	32 957
Fixed effects [¶]	-251	-425, -77	0.005		37.7	-6.7, 82.2	0.09		-0.20	-0.33, -0.06	0.005		32 957
Women													
Pooled OLS	48.7	-81, 178	0.5	<0.001	-2.2	-32.2, 27.8	0.9	<0.001	0.007	-0.11, 0.12	0.9	<0.001	35 343
Random effects	27.4	-114, 169	0.7	<0.001	-6.8	-40.0, 26.2	0.7	<0.001	0.002	-0.12, 0.13	0.9	<0.001	35 343
Fixed effects	-71.1	-227, 85	0.4		-16.1	-52.0, 19.8	0.4		-0.07	-0.21, 0.07	0.4		35 343

*Models were adjusted by age (modeled as log age), energy intake (continuous variable in kcal/d), per capita household income (continuous variable, inflated to 2015 Yuan values), urbanization index (continuous scale with possible values ranging from 0 to 120), health insurance (binary variable), an indicator variable of hypertension diagnosis from the second visit postdiagnosis onwards, and survey wave indicators.

[†]Pooled ordinary least-squares (OLS) regression using Stata's `reg` command with robust variance.

[‡]Specification test (F-test that all individual intercepts equal 0) comparing fixed-effects vs pooled OLS.

[§]Random-effects regression using Stata's `xtreg` command with the "re" option.

[¶]Hausman test comparing fixed-effects vs random-effects.

^{||}Fixed-effects regression using Stata's `xtreg` command with the "fe" option.

family (Table 3). Household average Na/K ratio decreased by 0.19 ($P=0.005$) when men were newly diagnosed with hypertension. When women were newly diagnosed, household changes were nonsignificant.

Sensitivity Analyses

Estimates for sodium and Na/K ratio from sensitivity analyses were similar in magnitude and statistical significance to our main analyses in men and women (Table 4). Models adjusted by BMI differed slightly from the main model, but mainly because of the change in sample size. Models that restricted analyses to the same sample that had BMI had almost identical estimates to the models adjusted by BMI. When we excluded observations with >4 years apart between waves, and individuals living in mega-cities, results were consistent for men and women. Models that were restricted to newly diagnosed and undiagnosed individuals were also consistent for men and women; however, change of sodium intake for women was higher in magnitude.

Discussion

We estimated the association between newly diagnosed hypertension and dietary changes measured as sodium intake, potassium intake, and Na/K ratio. We found that on average, men decreased their sodium intake by 251 mg/d and their Na/K ratio by 0.19, 2 to 4 years after receiving a hypertension diagnosis, after adjusting by covariates. Dietary changes also occurred at the household level when a man was newly diagnosed, with decreases in average sodium density (-8.3 mg/100 kcal) and average Na/K ratio (-0.19), and increases in average potassium density (1.6 mg/100 kcal). In married couples, women's dietary outcomes also improved when their husbands were newly diagnosed with hypertension. However, diagnosis for a woman does not seem to result in dietary changes for her or her household members. Sodium intake reductions have been shown to be beneficial for blood pressure reduction, especially among hypertensive patients.^{6–9}

Behavioral theories point out the importance of cues for promoting motivation for behavior change. One type of cue, called a "teachable moment," represents a health event that could promote improvement of health behaviors.⁴³ Diagnosis of hypertension could act as a "teachable moment," motivating individuals to modify their health behaviors and dietary intake towards healthier ones. Evidence from Canada showed that the main lifestyle modification associated with diagnosis of hypertension was smoking cessation; however, dietary behaviors were not assessed.⁴⁴ Manschot and colleagues also assessed lifestyle changes after a CVD or diabetes mellitus

Table 3. Change in Sodium, Potassium, and Sodium–Potassium Ratio Within 2 to 4 Years Associated With Newly Diagnosed Hypertension, Estimated Using Fixed-Effects Models, China Health and Nutrition Survey 1991–2015*

	Sodium [†]			Potassium [†]			Sodium–Potassium Ratio			N (Person-Observations)
	B	95% CI	P Value	β	95% CI	P Value	β	95% CI	P Value	
Men										
Overall [‡]	–251	–425, –77.2	0.005	37.7	–6.7, 82.2	0.09	–0.20	–0.33, –0.06	0.005	32 957
Diagnosed before wife [§]	–227	–444, –9.1	0.04	32.7	–25.1, 90.4	0.3	–0.22	–0.39, –0.05	0.01	17 297
Diagnosed after wife [§]	–224	–820, 373	0.5	–67.2	–180, 45.8	0.2	–0.07	–0.52, 0.37	0.7	16 761
Diagnosed at same wave as wife [§]	–311	–869, 247	0.3	–4.6	–143, 134	0.9	–0.27	–0.69, 0.15	0.2	13 806
Wife's change [§]	–229	–414, –43.3	0.02	29.1	–20.8, 78.9	0.3	–0.20	–0.36, –0.04	0.01	20 876
Household average density (mg/100 kcal) [‡]	–8.3	–16.4, –0.23	0.04	1.6	0.04, 3.1	0.04	32 957
Household average Na/K ratio [‡]	–0.19	–0.32, –0.06	0.005	32 957
Women										
Overall [‡]	–71.1	–227, 84.7	0.4	–16.1	–52.0, 19.8	0.4	–0.07	–0.21, 0.07	0.4	35 343
Diagnosed before husband [§]	–194	–414, 27.2	0.09	17.9	–32.1, 68.0	0.5	–0.19	–0.38, 0.01	0.06	16 764
Diagnosed after husband [§]	358	–97.6, 813	0.1	–14.6	–130, 100	0.8	0.22	–0.16, 0.61	0.3	17 299
Diagnosed at same wave as husband [§]	–120	–705, 465	0.7	48.3	–80.5, 177	0.5	–0.27	–0.74, 0.20	0.3	13 808
Husband's change [§]	–157	–365, 50.9	0.1	12.2	–41.7, 66.0	0.7	–0.15	–0.31, 0.01	0.07	20 875
Household average density (mg/100 kcal) [‡]	–6.2	–14.5, 2.1	0.1	–0.33	–1.9, 1.2	0.7	35 343
Household average Na/K ratio [‡]	–0.07	–0.2, 0.06	0.3	35 343

*Models were adjusted by age (modeled as log age), energy intake (continuous variable in kcal/d), per capita household income (continuous variable, inflated to 2015 Yuan values), urbanization index (continuous scale with possible values ranging from 0 to 120), health insurance (binary variable), an indicator variable of hypertension diagnosis from the 2nd visit postdiagnosis onwards, and survey wave indicators using Stata's –xtreg– command with the “fe” option, clustered at the individual level.

[†]Units are mg/d for sodium and potassium, except for household average density, which are mg/100 kcal.

[‡]Using complete sample; n men=7924, n women=8340.

[§]Restricted to head of household and his/her spouse; n=5286 couples, and the head of household could change between waves (eg, son of the head of household became the head of household in a following wave), 3.6% of households had >2 members during the whole observation period.

Table 4. Sensitivity Analyses for the Associations Between Newly Diagnosed Hypertension and Change in Sodium, Potassium, and Sodium–Potassium Ratio Using Fixed-Effects Regression: China Health and Nutrition Survey 1991–2015

	Sodium (mg/d)			Potassium (mg/d)			Sodium–Potassium Ratio			N (Person-Observations)
	β	95% CI	P Value	β	95% CI	P Value	β	95% CI	P Value	
Men										
Adjusting by BMI*	-209	-389, -29.2	0.02	36.1	-8.6, 80.7	0.1	-0.17	-0.31, -0.03	0.02	30 858
Restricted to adults with BMI data, without BMI adjustment*	-209	-388, -29.0	0.02	35.6	-9.2, 80.3	0.1	-0.16	-0.3, -0.02	0.02	30 858
Adjusted by marital status*	-250	-425, -75.9	0.005	36.6	-7.9, 81.0	0.1	-0.19	-0.33, -0.06	0.006	32 747
Restricted to adults with marital status data, without marital status adjustment*	-251	-425, -76.5	0.005	36.3	-8.1, 80.8	0.1	-0.20	-0.33, -0.06	0.005	32 747
Excluding observations with >4 y between waves*	-238	-423, -53.4	0.01	33.0	-14.7, 80.6	0.2	-0.19	-0.33, -0.04	0.01	29 700
Excluding adults from mega-cities*	-272	-449, -94.1	0.003	38.2	-7.6, 83.9	0.1	-0.21	-0.35, -0.07	0.003	31 461
Restricted to adults with newly diagnosed and undiagnosed hypertension*	-252	-446, -58.1	0.01	41.2	-7.6, 90.1	0.1	-0.21	-0.36, -0.06	0.007	11 965
Women										
Adjusting by BMI*	-65.9	-224, 92.3	0.4	-12.0	-49.1, 25.1	0.5	-0.05	-0.19, 0.09	0.5	33 872
Restricted to adults with BMI data, without BMI adjustment*	-64.3	-222, 93.5	0.4	-12.9	-50, 24.2	0.5	-0.05	-0.19, 0.1	0.5	33 872
Adjusted by marital status*	-69.6	-227, 87.4	0.4	-12.6	-48.7, 23.4	0.5	-0.07	-0.21, 0.07	0.3	35 068
Restricted to adults with marital status data, without marital status adjustment*	-64.6	-222, 92.5	0.4	-13.4	-49.4, 22.7	0.5	-0.07	-0.21, 0.08	0.4	35 068
Excluding observations with >4 years between waves*	-81.5	-245, 81.7	0.3	-21.0	-59, 17.1	0.3	-0.07	-0.21, 0.08	0.4	32 782
Excluding adults from mega-cities*	-82.8	-244, 77.8	0.3	-13.5	-50.4, 23.5	0.5	-0.08	-0.22, 0.07	0.3	33 619
Restricted to adults with newly diagnosed and undiagnosed hypertension*	-165	-346, 15.2	0.07	-24.5	-65.6, 16.6	0.2	-0.10	-0.26, 0.06	0.2	10 807

BMI indicates body mass index.
 *All other models were adjusted by age (modeled as log age), energy intake (continuous variable in kcal/d), per capita household income (continuous variable, inflated to 2015 Yuan values), urbanization index (continuous scale with possible values ranging from 0 to 120), health insurance (binary variable), an indicator variable of hypertension diagnosis from the second visit postdiagnosis onwards, and survey wave indicators using Stata's `-xtreg-` command with the "fe" option, clustered at the individual level.

diagnosis among Dutch adults. They found significant associations between CVD diagnosis and smoking cessation, and between diabetes mellitus diagnosis and weight loss, decreased energy intake, and increased fish intake.⁴⁵ The positive benefits of sodium reduction and potassium increase among hypertensive individuals on blood pressure control have been widely recognized, and current hypertension guidelines highlight the importance of these dietary factors for hypertension treatment and control.^{10,11,46,47} To the best of our knowledge, this is among the first studies to assess changes in dietary intake after receiving a diagnosis of hypertension using population-based data.

Studies on health literacy suggested that a substantial proportion of Chinese hypertensive adults (ranging from 52% to 95%) knew the effects of sodium on blood pressure.^{48–51} Similarly, between 75% and 90% reported taking actions to reduce their sodium intake, mainly by using less salt during food preparation.^{50,52,53} However, intention to reduce sodium intake might not always translate into actual reduction.²¹ In our study, we observed that 55% of men reduced 250 mg/d or more of sodium intake after being newly diagnosed with hypertension (data not shown). Interventions aimed at reducing sodium consumption through increased knowledge have been successful in countries where added salt is the major source.⁵⁴

Our results show a slight decline in sodium intake associated with hypertension diagnosis within 2 to 4 years after diagnosis. Evidence from a meta-analysis showed that among people with hypertension, a mean reduction of 1.7 g/d of sodium was associated with a mean change of -5.39 mm Hg for systolic blood pressure and -2.82 mm Hg for diastolic blood pressure.⁶ However, a sodium reduction intervention conducted in northern China estimated a reduction of 320 mg/d in sodium excretion but without significant changes in systolic blood pressure and diastolic blood pressure.⁵⁵ Noteworthy, the latter study included an important proportion of nonhypertensive adults; yet, effects of sodium reduction are stronger in hypertensive than in nonhypertensive adults.^{6,56} It is possible that the decline of 251 mg/d in sodium estimated in our study might not be enough to have meaningful changes in blood pressure levels. This modest change in sodium intake may reflect substantial difficulties and barriers faced by individuals when trying to reduce sodium intake. In a qualitative study, the main barrier to reduce sodium intake among Korean-Chinese adults was the difficulty associated with having meals with others —“when I have a meal with my family or friends, it is difficult to eat a reduced-sodium meal alone.”⁵⁷ Yet, our findings showed that when a man is newly diagnosed with hypertension, the household sodium density and the average Na/K ratio decreased, suggesting that all household adults decrease sodium intake.

We did not find evidence of an association between hypertension diagnosis and dietary changes in women, contrary to our expectations. Evidence from Western countries shows that women have better nutrition knowledge, are more interested in and reported being more active in seeking health-related information, and have higher diet-quality scores than men.^{58–61} Moreover, Chinese women (>18 years of age from a nationally representative sample) have been shown to have higher prevalence of hypertension control than men.⁵ In Chinese culture, dishes of prepared food are placed in the middle of the table for people to share; thus, all members eat from the same food preparation.³³ Furthermore, even though food preparation continues to be the responsibility of women in most Chinese households (90% of time dedicated to cooking in CHNS households was done by women), changes in salt content might not be accepted by other family members. Chinese power structure tends to be male dominant.⁶² Moreover, multigenerational households are common in China and preserve intergenerational hierarchy.⁶³ Thus, decision-making power of Chinese wives about salt use might be limited. Moreover, in a study about women’s perception of gender roles and decision-making, 60% of women agreed that “husband’s health is more important than wife’s in the family.”⁶⁴ Hence, women and other family members might be more willing to adapt to lower salt content in food when men are diagnosed, and not when women are diagnosed. With these data, we are not able to assess whether individuals are getting any type of advice from health providers, and whether it is differential between men and women. Yet, the heterogeneous association of results between men and women is worrisome considering the high prevalence of hypertension and CVD mortality among Chinese women.^{5,65}

Although the use of fixed-effects models allowed us to reduce the impact of confounding by time-invariant variables including unmeasured characteristics, we acknowledge that confounding can still be present because of time-varying factors. Moreover, fixed-effects models reduce variability by limiting estimations to within-individual change, incurring a loss of precision. Since being diagnosed with hypertension is not an exogenous event, there might be other factors associated with getting a diagnosis that might also be associated with reducing sodium intake. For instance, change in health awareness might come from another event (eg, death of a relative) that might motivate the individual to visit a physician and thus, get diagnosed, and to reduce sodium intake. Since randomization of hypertensive individuals to either receiving or postponing receiving a hypertension diagnosis would be unethical, it is not possible to fully examine this issue.

We also acknowledge that dietary measurements from self-reported 24-hour dietary recalls may be subject to measurement error and recall bias. Salt added during cooking at home

was the main source of sodium in the Chinese population, and salt along with other high-sodium condiments were weighed in the household inventory, reducing the likelihood of these issues. Main sources of potassium are fruits, vegetables, and legumes. These foods were self-reported in the repeated 24-hour recalls and might be more episodically consumed. Therefore, measurement error and recall bias could have affected potassium estimates more than sodium estimates, possibly biasing results towards the null.⁶⁶ However, our measure was validated against 24-hour urine excretion, showing strong correlation between sodium and potassium 24-hour urine excretion and our dietary intake estimates.¹⁴ Diet measures may be affected by social desirability bias,⁶⁷ and if it is a time-varying condition or if it changed after diagnosis, it could also bias our results. However, this bias would affect mainly self-reported data and not weighed household measurements. Sodium intake might be underestimated in later waves given the increase over time in food prepared and eaten away-from-home,⁶⁸ making it harder to have an accurate salt and condiments measure. If eating away-from-home is time-varying within individuals and correlated with hypertension diagnosis, it could also affect our results in later waves. Still, the proportion of total daily energy intake from food eaten away-from-home in 2011 was relatively small ($\approx 10\%$).⁶⁸

In spite of the abovementioned limitations, our study has several strengths. The CHNS is an ongoing 24-year population-based longitudinal study with repeated, detailed, and comparable diet data collected with 3-day 24-hour recalls and household food inventories. The combination of the 24-hour dietary recalls and the weighed household food inventory provided a unique opportunity to capture sodium intake. This allowed us to respond to a research question that has not been studied widely. Moreover, we applied fixed-effects methods, which reduce the threats imposed by confounders, and compared within-individual change in intake before and after diagnosis. In other words, fixed-effects models use each individual as his or her own control by comparing intake before and after hypertension diagnosis, while accounting for secular trends occurring during the study period. Finally, our results were robust to alternative model specifications and sample selection for sodium and Na/K ratio.

The American College of Cardiology/American Heart Association recently released their updated hypertension guidelines,⁶⁹ with one of their major features being the change in the definition of hypertension from $\geq 140/90$ to $\geq 130/80$ mm Hg. As previously mentioned, a nationwide survey conducted in China estimated that 23% of adults had hypertension. With the new American College of Cardiology/American Heart Association definition, the prevalence of hypertension would increase to 46% of adults.⁵ Adoption of the new American College of Cardiology/American Heart

Association hypertension criterion may occur over time in the Chinese hypertension guidelines.⁷⁰ If the higher prevalence of hypertension is also accompanied by a higher number of diagnosed cases, and if the declines in sodium intake we estimated associated with hypertension diagnosis also occur in the newly diagnosed adults, a larger sodium decline at the population level could likely be expected. However, we cannot be certain the association we estimated would remain under the new American College of Cardiology/American Heart Association hypertension definition. Yet, the already high prevalence of hypertension in Chinese adults, coupled with the low control rates, emphasize the need to improve nonpharmacological approaches for hypertension prevention and control.

The burden of hypertension constitutes a major public health challenge both worldwide and in China. Decreasing sodium intake and increasing potassium has a significant impact on reducing blood pressure, especially among hypertensive individuals.^{6-9,13} Likewise, sodium reduction prevents cardiovascular events and reduces mortality risk, and is one of the most cost-effective interventions for preventing noncommunicable diseases.^{10-12,71} Our results indicate modest changes in sodium intake, potassium intake, and Na/K ratio following hypertension diagnosis in Chinese men. Thus, these results shed light on the association between diagnosis and dietary changes, suggesting that diagnosis may have a positive effect on diet. However, we did not observe this estimated effect in women. Therefore, there is a need to further examine these sex differences to understand what motivates men and their family members to make dietary changes after a hypertension diagnosis for a man. There is also a need to identify the reasons why a woman's diagnosis does not translate to meaningful dietary changes for her or her household. Additionally, given the observed benefits of diagnosis, efforts to increase hypertension diagnosis in China should continue.⁵ Further research is still needed to understand whether changes in diet after hypertension diagnosis are sustained in the long term and whether such diagnosis-induced dietary changes are sufficient to lead to blood pressure reduction.

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Disclosures

None.

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SUPPLEMENTAL MATERIAL

Table S1. Sodium intake, potassium intake, and Na/K ratio by sex and survey wave, China Health and Nutrition Survey 1991-2015.

	Men				Women			
	n	Sodium (mg/d)*	Potassium (mg/d)	Na/K	n	Sodium (mg/d)	Potassium (mg/d)	Na/K
1991	2,850	6,414 (3,063)	1,804 (620)	3.86 (2.23)	3,147	6,180 (2,933)	1,627 (556)	4.11 (2.31)
1993	2,931	6,236 (2,920)	1,784 (656)	3.88 (2.43)	3,253	6,038 (2,819)	1,613 (640)	4.11 (2.27)
1997	3,619	5,869 (3,067)	1,751 (775)	3.73 (2.52)	3,645	5,674 (3,011)	1,575 (774)	3.99 (2.48)
2000	3,610	5,831 (2,855)	1,737 (800)	3.72 (2.11)	3,815	5,544 (2,692)	1,544 (772)	4.01 (2.30)
2004	3,891	5,026 (2,585)	1,682 (681)	3.29 (1.97)	4,105	4,698 (2,443)	1,506 (641)	3.48 (2.11)
2006	3,837	4,770 (2,452)	1,746 (809)	3.04 (1.85)	4,122	4,529 (2,370)	1,557 (728)	3.23 (1.92)
2009	3,991	4,511 (2,273)	1,763 (672)	2.82 (1.71)	4,195	4,218 (2,199)	1,564 (656)	2.99 (1.83)
2011	4,441	4,502 (2,153)	1,708 (784)	2.99 (1.84)	4,903	4,215 (2,107)	1,513 (695)	3.18 (2.09)
2015	3,787	4,174 (2,247)	1,601 (661)	2.94 (1.95)	4,158	3,876 (2,097)	1,428 (648)	3.10 (2.29)

*Values are means (standard deviation).