Received: 29 March 2022 | Revised: 27 May 2022 | Accepted: 30 May 2022

DOI: 10.1111/jch.14533

ORIGINAL ARTICLE

WILEY

Association of cooking fuel with incident hypertension among adults in China: A population-based cohort study

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Funding information
National Natural Science Foundation of China, Grant/Award Number: 81903416

Abstract

With an increasing prevalence of hypertension, indoor air-pollution factors began to attract extensive attention. However, the association of cooking fuel with the incidence of hypertension was inconsistent. The aim of this study was to investigate the association of household air-pollution caused by cooking fuel with the incidence of hypertension. Data were derived from the China Health and Nutrition Survey. Participants aged 18 years or older were eligible. A validated questionnaire was used to collect the information on the type of cooking fuel, including electricity, natural gas, coal, and wood/charcoal. Participants with a systemic blood pressure (SBP) ≥ 140 mmHg or /and a diastolic blood pressure (DBP) ≥ 90 mmHg without use of anti-hypertensive medications, or participants with an SBP/DBP < 140/90 mmHg but having hypertensive history or currently being taking anti-hypertensive medication were identified as hypertension. Multilevel Cox regressions were employed to examine the association of cooking fuel with incident hypertension. Compared to participants using electricity, participants using wood/charcoal had a higher incidence of hypertension (HR: 1.581; 95% CI: 1.373-1.821; and *P* < .001), which was independent of sex and living areas. Furthermore, this significant association was observed only in the participants aged 18–39 years (HR: 1.443; 95% CI: 1.131-1.840; and *P* = .003). Compared to participants using non-polluting energy, participants using solid fuel were more likely to develop hypertension (HR: 1.309; 95% CI: 1.191-1.439; and *P* < .001). In conclusion, household air-pollution was associated with the incidence of hypertension among Chinese adults. Using wood/charcoal or solid fuel in youth was associated with a higher incidence of hypertension later in life.

KEYWORDS
cooking fuel, household air-pollution, incident hypertension, solid fuel

1 | INTRODUCTION

As the leading modifiable risk factor of cardiovascular disease (CVD), the prevalence of hypertension has been increasing, and the number of people with hypertension is expected to increase to 1.56 billion in 2025.[1,2] Therefore, hypertension has become a common global public health issue. In recent decades, some epidemiological studies have evaluated the relationships between exposure to ambient air

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pollutants and hypertension, and suggested that air pollution was an independent environmental risk factor of hypertension.[3] As a part of air pollution, household air pollution has been become a major environmental exposure, and affects billions of people every year.[4] Household solid fuel (such as coal, wood, charcoal) combustion was the main source of household air pollution.[5] In low and middle-income countries, there are nearly 3 billion people using solid fuel for cooking and heating, and this number is expected to grow until at least 2030.[6] In China, almost half of families use solid fuel for cooking.[7]

Some studies have been conducted to examine the associations of biomass smoke exposure with CVD, stroke, and hypertension.[8] Although increasing studies have investigated the association of solid fuel with the incidence of hypertension, the conclusions were controversial.[5,9–12] On the basis of existing researches and the rapidly increasing prevalence of hypertension, further evidence on the association of cooking fuel with the incidence of hypertension is imperative.

In the present study, we used the data from a 26-year representative national cohort study to investigate the association of cooking fuel with the incidence of hypertension. Furthermore, multilevel model was used to correct the cluster effect of family. It is expected that this study would provide new viewpoints and suggestions for prevention and control of hypertension.

2 | MATERIAL AND METHODS

2.1 | Study design and population

We analyzed the data of the China Health and Nutrition Survey (CHNS), which was launched by the Chinese government in 1989, and followed by waves 1991, 1993, 1997, 2000, 2004, 2006, 2008, 2011, and 2015. Since wave 1997, additional households were added to replace those no longer participating. Since wave 2011, three megacities (Beijing, Chongqing, and Shanghai) were added. Since wave 2015, three new provinces (Shaanxi, Yunnan, and Zhejiang) were added. A multistage random cluster process was employed to create a sample in 15 provinces and municipal cities, which were randomly selected to ensure the representative of sample in geography, economic development, public resources, and health indicators. A validated questionnaire was used to collect information on household survey, nutrition survey, physical examination, and so on. The detailed survey design and procedures have been described elsewhere.[13] This study was approved by the Institutional Review Board of the National Institute for Nutrition and Food Safety, China Center for Disease Control and Prevention, and University of North Carolina at Chapel Hill. All participants provided written informed consent.

All participants aged 18 years or older at baseline were eligible in this study. The exclusion criteria were as follows: participants had missing data on cooking fuel at each wave and on covariates at baseline; participants failed to finish measurement of blood pressure at each wave; and participants were pregnant or lactating at baseline. The detailed process of participants selection is shown in Figure 1.

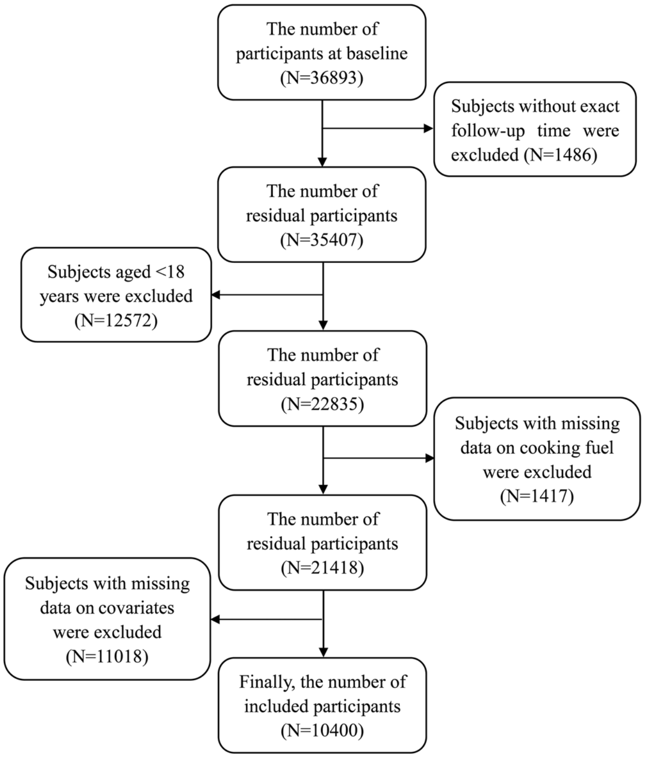

FIGURE 1 The detailed process of participants selection in this study

2.2 | Type of cooking fuel

The type of household cooking fuel was identified via a question: What type of fuel does your household generally use for cooking? The householder was interviewed to provide the exact type of cooking fuel from the following options: 1. coal, 2. electricity, 3. kerosene, 4. liquified natural gas, 5. natural gas, 6. wood or sticks/straw, and 7. charcoal. If more than one type of cooking fuel was provided, the most commonly used fuel was recorded. In this study, the type of cooking fuel was reclassified as follows: 1. electricity, 2. natural gas, including liquified natural gas and natural gas, 3. coal, and 4. wood/charcoal, including wood or sticks/straw and charcoal. Since there were very few households to use kerosene (n = 77), cooking fuel of kerosene was not involved in this study. Furthermore, we dichotomized cooking fuel as non-polluting energy including electricity and natural gas as well as solid fuel including coal and wood/charcoal.

2.3 | Measurement of blood pressure and the definition of hypertension

Each participant was required to measure blood pressure each wave by trained health workers following standardized protocols. Participants were required to rest for 10 min in the seated position prior to measure of blood pressure. A suitable cuff size was chosen according to the upper arm circumference. Standard mercury sphygmomanometer was used to measure diastolic blood pressure (DBP) and systemic blood

TABLE 1 Characteristics of all participants at baseline

Characteristics	Total (No. = 10 400)	End-event Non-hypertension (No. = 6150)	End-event Hypertension (No. = 4250)	*P*
Age (years)[a]	44.44 ± 15.42	39.26 ± 13.75	51.93 ± 14.60	<.001
BMI (kg/m^2)[a]	23.42 ± 3.68	22.68 ± 3.51	24.48 ± 3.67	<.001
Sex[b]				<.001
Males	4531(43.57)	2381(38.72)	2150(50.59)	
Females	5869(56.43)	3769(61.28)	2100(49.41)	
Marital status[b]				<.001
Married	733(7.05)	596(9.69)	137(3.22)	
Divorced /Widowed	8886(85.44)	5250(85.37)	3636(85.55)	
Unmarried	781(7.51)	304(4.94)	477(11.22)	
Living areas[b]				.097
Urban	5030(48.37)	3016(49.04)	2014(47.39)	
Rural	5370(51.63)	3134(50.96)	2236(52.61)	
Education[b]				<.001
Primary school or below	3250(31.25)	1475(23.98)	1775(41.76)	
Middle school	5880(56.54)	3710(60.33)	2170(51.06)	
College or above	1270(12.21)	965(15.69)	305(7.18)	
Ethnicity[b]				<.001
Han	9513(91.47)	5529(89.90)	3984(93.74)	
Others	887(8.53)	621(10.10)	266(6.26)	
Current smoker[b]				<.001
No	7406(71.21)	4613(75.01)	2793(65.72)	
Yes	2994(28.79)	1537(24.99)	1457(34.28)	
Current alcohol consumer[b]				<.001
No	6898(66.33)	4231(68.80)	2667(62.75)	
Yes	3502(33.67)	1919(31.20)	1583(37.25)	
Gross family income[b]				<.001
Low	2731(26.26)	1455(23.66)	1276(30.02)	
High	7669(73.74)	4695(76.34)	2974(69.98)	
Physical activity[b]				.071
No	8551(82.22)	5022(81.66)	3529(83.04)	
Yes	1849(17.78)	1128(18.34)	721(16.96)	
History of diabetes[b]				<.001
No	10 062(96.75)	6069(98.68)	3993(93.95)	
Yes	338(3.25)	81(1.32)	257(6.05)	
History of CVD[b]				<.001
No	10 236(98.42)	6120(99.51)	4116(96.85)	
Yes	164(1.58)	30(0.49)	134(3.15)	
Intake of fast food[b]				<.001
No	7820(75.19)	4308(70.05)	3512(82.64)	
Yes	2580(24.81)	1842(29.95)	738(17.36)	
Intake of salty snack food[b]				<.001
No	7109(68.36)	3924(63.80)	3185(74.94)	
Yes	3291(31.64)	2226(36.20)	1065(25.06)	

(Continues)

TABLE 1 (Continued)

Characteristics	Total (No. = 10 400)	End-event Non-hypertension (No. = 6150)	Hypertension (No. = 4250)	P
Intake of fruits[b]				.001
No	591(5.68)	311(5.06)	280(6.59)	
Yes	9809(94.32)	5839(94.94)	3970(93.41)	
Intake of vegetables[b]				.185
No	232(2.23)	147(2.39)	85(2.00)	
Yes	10 168(97.77)	6003(97.61)	4165(98.00)	
Intake of soft/sugared drinks[b]				<.001
No	5380(51.73)	2877(46.78)	2503(58.89)	
Yes	5020(48.27)	3273(53.22)	1747(41.11)	
Type of cooking fuel[b]				<.001
Electricity	1861(17.89)	1189(19.33)	672(15.81)	
Natural gas	5327(51.22)	3165(51.46)	2162(50.87)	
Coal	1705(16.39)	1037(16.86)	668(15.72)	
Wood/charcoal	1507(14.49)	759(12.34)	748(17.60)	

BMI, body mass index, CVD, cardiovascular diseases.
[a]These variables were analyzed using *t*-test.
[b]These variables were analyzed using chi-square test.

pressure (SBP), which were indicated by the first and fifth Korotkoff sounds, respectively. The averages of three measures were used in the final analysis. If participants with a SBP ≥ 140 mmHg or /and a DBP ≥ 90 mmHg without use of anti-hypertensive medications, or participants with a SBP/DBP < 140/90 mmHg but having hypertensive history or currently being taking anti-hypertensive medication, they were identified as hypertension.[14] As the end-event, hypertension was assessed in each wave for each participant. If hypertension was firstly identified in a certain wave, participant was considered to have the end-event, and the exact time when firstly diagnosed with hypertension was recorded.

2.4 | Statistical analysis

Age and body mass index (BMI) were expressed as means ± standard deviations, and were compared between non-hypertension and hypertension groups using *t*-test. Categorized variables were described as frequencies (constituent ratios), and were compared between non-hypertension and hypertension groups using chi-square tests. Since data on cooking fuel were collected in household level, there might be family cluster in the data of individual level. Therefore, multilevel *Cox* regressions were employed to examine the association of cooking fuel with the incidence of hypertension, and calculate hazard ratios (HRs) and 95% confidential intervals (CIs). In multilevel Cox regression, household was considered as a high level and treated as a random effect term, and individual was considered as a low level and treated as a fixed effect term. The new onset hypertension was considered as the end-event. Time interval from the baseline to the occurrence of hypertension, death, loss to follow-up, or the end of this study, whichever came first, was considered as the time variable. All *Cox* regressions adjusted for age, sex, BMI, ethnicity, education levels, marital status, gross family income, current smoker, current alcohol consumer, physical activity, history of diabetes and CVD, dietary intake of fast food, salty snack food, fruits, vegetables and soft/sugared drinks, and death status. Furthermore, *Cox* regressions were further stratified by age, sex, and living areas. The proportional hazards assumption held in all *Cox* regressions. Additionally, three sensitivity analyses were conducted in this study. First, participants might enter into this cohort in different waves, the first sensitivity analysis was conducted to adjust for different waves. Second, given use of cooking fuel might change over 26-year follow- up period, the second sensitivity analysis was conducted with cooking fuel as a time-dependent variable. Third, a Fine-Gray competing risk model was used to correct the competitive risk of death in the third sensitivity analysis. All analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Statistical significance was identified when a two-tailed $P \leq .05$.

3 | RESULTS

3.1 | Characteristics of study participants

A total of 10 400 participants were included in this study. The means ± standard deviations of age and BMI were 44.44 ± 15.42 years and 23.42 ± 3.68 kg/m^2, respectively. There were 4250 participants suffering from the end-event of hypertension. The proportions of male and female were 43.57% and 56.43%, respectively. The baseline characteristics of all participants are shown in Table 1. Significant differences between non-hypertension and hypertension groups were observed

TABLE 2 The association of cooking fuel with the incidence of hypertension

Models	HR	95% CI	*P*
Total (No. = 10 400)[a]			
Electricity	Ref		
Natural gas	1.016	0.910-1.135	.780
Coal	1.142	0.994-1.312	.061
Wood/charcoal	1.581	1.373-1.821	<.001
Males (No. = 4531)[b]			
Electricity	Ref		
Natural gas	1.007	0.874-1.161	.923
Coal	1.093	0.912-1.311	.335
Wood/charcoal	1.464	1.216-1.763	<.001
Females (No. = 5869)[b]			
Electricity	Ref		
Natural gas	0.987	0.851-1.145	.865
Coal	1.152	0.958-1.385	.132
Wood/charcoal	1.634	1.357-1.968	<.001
Urban (No. = 5030)[c]			
Electricity	Ref		
Natural gas	0.970	0.839-1.123	.685
Coal	1.078	0.874-1.328	.483
Wood/charcoal	1.420	1.076-1.874	.013
Rural (No. = 5370)[c]			
Electricity	Ref		
Natural gas	1.053	0.889-1.247	.549
Coal	1.221	1.010-1.477	.039
Wood/charcoal	1.785	1.487-2.141	<.001

[a]Age, sex, BMI, education levels, marital status, living areas, gross family income, current smoker, current alcohol consumer, physical activity, ethnicity, history of diabetes, dietary intake of fast food, salty snack food, fruits, vegetables and soft/sugared drinks, and death status were adjusted.
[b]Age, BMI, education levels, marital status, living areas, gross family income, current smoker, current alcohol consumer, physical activity, ethnicity, history of diabetes, dietary intake of fast food, salty snack food, fruits, vegetables and soft/sugared drinks, and death status were adjusted.
[c]Age, sex, BMI, education levels, marital status, gross family income, current smoker, current alcohol consumer, physical activity, ethnicity, history of diabetes, dietary intake of fast food, salty snack food, fruits, vegetables and soft/sugared drinks, and death status were adjusted.

in all characteristics, except living areas (P = .097), physical activity (P = .071), and intake of vegetables (P = .185).

3.2 | The association of cooking fuel with the incidence of hypertension

The association of cooking fuel with the incidence of hypertension is shown in Table 2. Compared to participants using electricity, participants using wood/charcoal had a higher incidence of hypertension in the total sample, and the incidence of hypertension would increase by 58.1% (*HR*: 1.581; 95% CI: 1.373-1.821; and P < .001). However, there were no significant associations of natural gas and coal with the incidence of hypertension (P = .780 and .061, respectively). The results stratified by sex were consistent with those of the total sample. However, coal use was associated with an increased incidence of hypertension in the rural areas (HR: 1.221; 95% CI: 1.010-1.477; and P = .039). In addition, when stratified by age, wood/charcoal use was associated with a higher risk of hypertension in the participants aged 18–39 years (HR: 1.367; 95% CI: 1.104-1.692; and P = .004), and natural gas use was associated with a higher risk of hypertension in the participants aged 60–100 years (HR: 1.325; 95% CI: 1.110-1.582; and P = .002). However, after adjusting for covariates, a significant association of wood/charcoal with the incidence of hypertension was observed only in the participants aged 18–39 years (HR: 1.443; 95% CI: 1.131-1.840; and P = .003), as shown in Figure 2.

TABLE 3 The association of cooking fuel, as a dichotomous variable, with the incidence of hypertension

Models	HR	95% CI	*P*
Total population (No. = 10 400) [a]			
Non-polluting energy	Ref		
Solid fuel	1.309	1.191-1.439	<.001
Males (No. = 4531) [b]			
Non-polluting energy	Ref		
Solid fuel	1.239	1.094-1.404	.001
Females (No. = 5869) [b]			
Non-polluting energy	Ref		
Solid fuel	1.362	1.203-1.542	<.001
Urban (No. = 5030) [c]			
Non-polluting energy	Ref		
Solid fuel	1.194	1.023-1.394	.025
Rural (No. = 5370) [c]			
Non-polluting energy	Ref		
Solid fuel	1.441	1.275-1.629	<.001

[a]Age, sex, BMI, education levels, marital status, living areas, gross family income, current smoker, current alcohol consumer, physical activity, ethnicity, history of diabetes, dietary intake of fast food, salty snack food, fruits, vegetables and soft/sugared drinks, and death status were adjusted.
[b]Age, BMI, education levels, marital status, living areas, gross family income, current smoker, current alcohol consumer, physical activity, ethnicity, history of diabetes, dietary intake of fast food, salty snack food, fruits, vegetables and soft/sugared drinks, and death status were adjusted.
[c]Age, sex, BMI, education levels, marital status, gross family income, current smoker, current alcohol consumer, physical activity, ethnicity, history of diabetes, dietary intake of fast food, salty snack food, fruits, vegetables and soft/sugared drinks, and death status were adjusted.

In Table 3, compared to non-polluting energy, solid fuel was associated with an increased risk of hypertension, which would increase by 30.9% (HR: 1.309; 95% CI: 1.191-1.439; and P < .001). When stratified by sex and living areas, the results were comparable with those of the

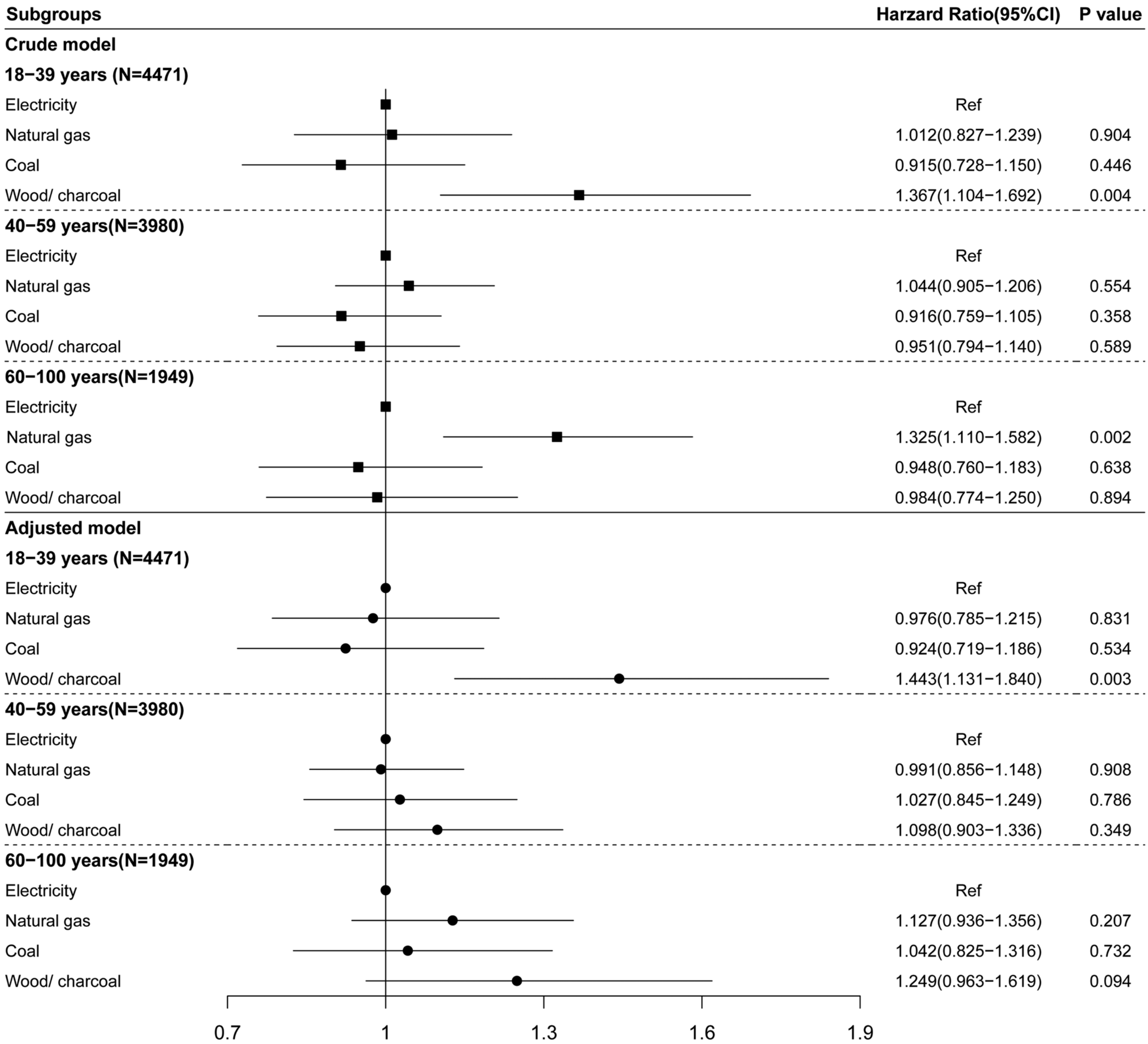

FIGURE 2 The association of cooking fuel with the incidence of hypertension stratified by age

total sample. However, when stratified by age, a negative association of solid fuel with the incidence of hypertension was observed only in the participants aged 60–100 years (HR: 0.778; 95% CI: 0.677-0.893; and $P < .001$). As adjusting for covariate, the significant relationships between solid fuel and the incidence of hypertension disappeared in all age-groups, although the association of solid fuel with the risk of hypertension was really close to 0.05 in the participants aged 18–39 years ($P = .066$), as shown in Figure 3.

3.3 | Sensitivity analysis

Firstly, when additionally adjusting for waves, the results did not substantially change. Use of wood/charcoal or solid fuel was associated with an increased risk of hypertension (HR: 1.348 and 1.138; 95% CI: 1.165-1.559 and 1.032-1.255; and $P < .001$ and $= .010$, respectively) as shown in Table S1.

Secondly, when cooking fuel as a time-dependent variable, participants using wood/charcoal or solid fuel had an increased incidence of hypertension (HR: 1.235 and 1.116; 95% CI: 1.078-1.415 and 1.003-1.242; and $P = .002$ and .043, respectively) as shown in Table S2. Therefore, the result of sensitivity analysis was comparable with the main results.

Thirdly, a Fine-Gray competing risk model was used to correct the competitive risk of death. It showed that the associations of wood/charcoal and solid fuel with the incidence of hypertension were similar to the main results (HR: 1.311 and 1.152; 95% CI: 1.170-1.470 and 1.066-1.245; and both $P < .001$, respectively) as shown in Table S3.

4 | DISCUSSION

This large-scale prospective cohort study found that participants using wood/charcoal fuel or solid fuel were more likely to develop

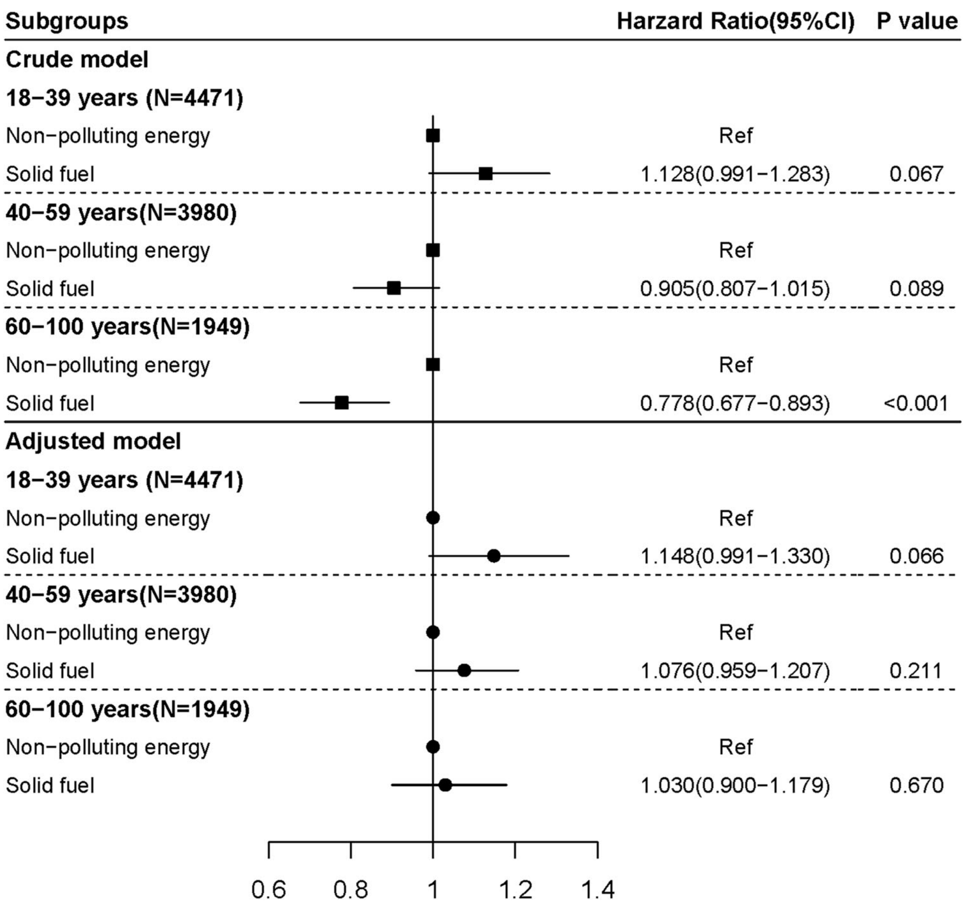

FIGURE 3 The association of cooking fuel as a dichotomous variable with the incidence of hypertension stratified by age

hypertension, which was independent of sex and living areas. Furthermore, the significant association of wood/charcoal with the incidence of hypertension was fully observed in young adults but not in the elderly.

The association of wood/charcoal fuel use with the incidence of hypertension in this study was consistent with previous studies. [15,16] A study in Peru showed that biomass users had increased risks of both prehypertension and hypertension.[17] A cohort study also found a positive association of biomass fuel use with the risk of hypertension among Chinese adults.[5] Another study from China showed that there were positive associations of solid fuel use with the risks of cardiovascular and all-cause mortality.[18] Since hypertension is closely related to cardiovascular health, it was rational that solid fuel use linked to an increased risk of hypertension. However, some studies reported an opposite or insignificant association, which may be due to differences in study populations,[19] study design,[10] and exposure sources.[12] Different fuels have varied effect sizes on hypertension because they have different burning efficiency and different contents of air pollution.[7]

The underlying mechanisms on how cooking fuel affected development of hypertension remained currently unclear. It was speculated that the toxic pollutant and fine particulate matter released by the combustion of biomass fuels were the potential causes. It was documented that a large amount of particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide, nitrogen dioxide, sulfur dioxide, and other volatile organic compounds will be produced during burning solid fuel.[20] These chemical substances could increase oxidative stress and systematic inflammation, and potentially increase blood pressure and atherosclerosis.[21,22] Previous study found that participants exposed to solid fuel for heating and cooking would have a twice higher $PM_{2.5}$ exposure value than those using electricity.[23] Meanwhile, previous study found that burning wood or plant materials resulted in a higher concentration of $PM_{2.5}$ than coal,[24] which supported the finding of this study that wood/charcoal but not coal was associated with a higher incidence of hypertension.

This study found that exposed to wood/charcoal fuel in youth was associated with an increased risk of hypertension later in life. Younger ages represent human being with lesser comorbid diseases mediated by age. Hence a scenario, the environmental effect may be detached easier. As a result, less obscured by co-morbid illnesses and competing biologic forces drive the emergence of hypertension. However, no significant association of cooking fuel with the risk of hypertension was observed in the elderly in this study, which was consistent with previous studies.[9,25] One of these studies found a significant association of indoor solid fuel with hypertension among adults aged ≤ 50 years but not in the elderly aged > 50 years.[25] Furthermore, another study showed that no significant relationship between solid fuel use and hypertension was observed in the elderly ≥ 60 years.[12] These studies implied the variability of the association of cooking fuel use with hypertension. On the other hand, since a Fine-Gray competing risk model cannot be used together with multilevel Cox regression, death status was adjusted only as a confounding factor in multilevel *Cox* regression. However, a Fine-Gray competing risk model was used to correct the competitive risk of death in the sensitivity analysis, and the results remained unchanged. Therefore, the finding of this study was stable and credible.

4.1 | Strengths and limitations

Some impressive strengths in this study should be stated. First, this study was a large-scale and long-term follow-up population-based cohort study. Therefore, the findings on the association of cooking fuel with the incidence of hypertension were convictive. Second, this study found that exposed to household air-pollution in youth was significantly associated with the risk of hypertension later in life. Therefore, this study would contribute to the precision prevention of hypertension.

However, there were some limitations to be stated. First, since heating fuel was not collected in the CHNS, only cooking fuel but not heating fuel was involved in this study. On the other hand, data on the frequency of cooking fuel use were also not collected, which implied that the influence of the frequency of cooking fuel use failed to be corrected. Second, household air pollution might be influenced by ventilation level, climatic conditions, and fuel properties,[26] which were not considered in this study. Third, since a part of information analyzed in this study were collected by self-report, there might be information bias. Fourth, the study population limited to Chinese, it should be cautious to extrapolate the conclusions to other populations.

5 | CONCLUSIONS

The type of cooking fuel was associated with the incidence of hypertension among Chinese adults. Use of wood/charcoal as cooking fuel linked to a higher risk of hypertension. Similarly, compared to non-polluting energy, solid fuel was associated with an increased incidence of hypertension. Furthermore, the significant associations were independent of sex and living areas but dependent of age. Those exposed to wood/charcoal or solid fuel in youth were more likely to develop hypertension later in life. Therefore, it is crucial to reduce indoor air pollution from solid fuel by using non-polluting energy. Meanwhile, more attention should be paid to those exposed to solid fuel in youth.

ACKNOWLEDGEMENT

This research uses data from China Health and Nutrition Survey (CHNS). We thank the National Institute for Nutrition and Health, China Center for Disease Control and Prevention, Carolina Population Center, the University of North Carolina at Chapel Hill, the NIH and the NIH Fogarty International Center for support for the CHNS data collection and analysis files from 1989 to 2015 and future surveys, and the China-Japan Friendship Hospital, Ministry of Health for support for CHNS 2009, Chinese National Human Genome Center at Shanghai since 2009, and Beijing Municipal Center for Disease Prevention and Control since 2011.

This work was supported by the National Natural Science Foundation of China (81903416). The funding body did not play any roles in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

Yue Peng wrote the draft paper, Yu Wang revised the manuscript and improved the language, Fei Wu analyzed the data and interpreted the results, and Yongjie Chen designed the study. All authors have approved the final article.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Peng Y, Wang Y, Wu F, Chen Y. Association of cooking fuel with incident hypertension among adults in China: A population-based cohort study. *J Clin Hypertens*. 2022;24:1003–1011.
https://doi.org/10.1111/jch.14533