



Association of Household Utility of Cleaner Fuel With Lower Hypertension Prevalence and Blood Pressure in Chinese Adults

Zhiguang Liu^{1†}, Mengya Li^{2†}, Yibing Zhu³, Perry Hystad⁴, Yuanting Ma⁵, Sumathy Rangarajan⁶, Qian Zhao⁷, Lihua Hu⁸, Salim Yusuf⁶, Yang Li^{2*†} and Lap Ah Tse^{9*†} on behalf of PURE-China Investigators

¹Department of Pharmacy and Clinical Trial Unit, Beijing Anzhen Hospital, Capital Medical University, Beijing, China, ²Medical Research and Biometrics Center, National Clinical Research Center for Cardiovascular Diseases, Fuwai Hospital, National Center for Cardiovascular Diseases, Peking Union Medical College and Chinese Academy of Medical Sciences, Beijing, China, ³Department of Emergency, Guang'anmen Hospital, China Academy of Chinese Medical Sciences, Beijing, China, ⁴School of Biological and Population Health Sciences, College of Public Health and Human Sciences, Oregon State University, Corvallis, OR, United States, ⁵Dongguan street Community Health Service Center, Xining, China, ⁶Population Health Research Institute, McMaster University and Hamilton Health Sciences, Hamilton, ON, Canada, ⁷General Practice Ward/International Medical Center Ward, General Practice Medical Center, West China Hospital, Sichuan University, Chengdu, Sichuan, China, ⁸Nanchang Center for Disease Control and Prevention, Nanchang, China, ⁹JC School of Public Health and Primary Care, The Chinese University of Hong Kong, Hong Kong, Hong Kong SAR, China

OPEN ACCESS

Edited by:

Nino Kuenzli,
 Swiss Tropical and Public Health
 Institute (Swiss TPH), Switzerland

*Correspondence:

Lap Ah Tse
 shelly@cuhk.edu.hk
 Yang Li
 liyang@mrbcc-nccd.com

[†]These authors have contributed
 equally to this work and share first
 authorship

[‡]These authors have contributed
 equally to this work

Received: 07 July 2022

Accepted: 22 September 2022

Published: 24 November 2022

Citation:

Liu Z, Li M, Zhu Y, Hystad P, Ma Y, Rangarajan S, Zhao Q, Hu L, Yusuf S, Li Y and Tse LA (2022) Association of Household Utility of Cleaner Fuel With Lower Hypertension Prevalence and Blood Pressure in Chinese Adults. *Int J Public Health* 67:1605193. doi: 10.3389/ijph.2022.1605193

Objectives: To investigate whether lower hypertension prevalence or blood pressure was associated with cleaner household fuel usage for cooking and heating among Chinese adults.

Methods: We enrolled 44,862 Chinese adults at the baseline of the prospective urban and rural epidemiology (PURE) study in China during 2005–2009, as a subset of the PURE-global China site. Multilevel logistic regression and generalized linear mixed models were conducted to estimate the adjusted odds ratio (AOR) and regression coefficient for hypertension and blood pressure respectively, while subgroup analysis by ambient PM2.5 concentration and location was also examined.

Results: Compared with the least clean household solid fuel group, gas (AOR = 0.91, 95% CI: 0.83, 0.99) or electricity (AOR = 0.72, 95% CI: 0.60, 0.87) was associated with significantly lower levels of hypertension prevalence and blood pressure, and a similar pattern of the association was consistently observed among participants with high ambient PM2.5 exposure and those living in urban areas.

Conclusion: Household utility of cleaner fuel type was associated with lower hypertension prevalence and blood pressure in Chinese adults. Our study urges the utilization of cleaner household energy to mitigate the burden of hypertension.

Keywords: hypertension, air pollution, biomass, household fuel use, solid fuel, energy ladder, cleanliness

Abbreviations: AOR, Adjusted odds ratio; BMI, Body mass index; CI, Confidence interval; DBP, Diastolic blood pressure; DHS, Demographic and Health Surveys; IQR, interquartile range; OR, Odds ratio; PURE, the Prospective Urban and Rural Health Evaluation Study; PM 2.5: Particulate Matter 2.5; SBP, Systolic blood pressure; SD, standard deviation.

INTRODUCTION

Growing epidemiological evidence has shown that air pollution is one of the most important risk factors for increasing the global burden of cardiovascular diseases and all-cause mortality [1–5]. Current research demonstrated that household air pollution generated from burning solid fuel could cause more deaths than that of the ambient air pollution (3.5 million vs. 3.1 million) [6]. Despite household facilities for cooking and heating having been greatly improved in recent years [7, 8], household air pollution remains the leading risk factor associated with increased mortality in the east of Asia [5, 9]. Previous epidemiological studies in South America, Africa, India, and China have investigated the association between household air pollution emitted from burning household solid fuels for cooking and hypertension prevalence, using the clean fuels as a comparison (i.e., combined gas and electricity), but obtained inconsistent findings [10–14]. Few of them specified the individual fuel type for cooking according to energy efficiency, classified by the level of cleanliness of the fuel determined by their potential emission amount of particulate matters during combustion, i.e., from solid fuel (the lowest cleanliness), liquid, gas, to electricity (the highest cleanliness) [15], while the association with household fuel uses for heating were not specifically addressed in the previous studies. Household gas fuel is widely regarded as clean energy, however, results from an experimental study revealed that the median concentration of PM_{2.5} was substantially higher in kitchens using gas-fueled stoves than in kitchens using electric induction cookers (0.281 mg/m³ vs. 0.155 mg/m³) [16]. To date, evidence has been lacking on the association of hypertension or blood pressure with different types of household fuel use for cooking and heating. Moreover, it is likely that the hazardous effect of utilizing less clean household fuels on hypertension and blood pressure may become stronger among residents with relatively high ambient PM_{2.5} exposure, resulting from cumulative inflammation and injury in the vascular endothelium induced by the toxic effects of the indoor and outdoor PM_{2.5} air pollution [17]. Nevertheless, this potential interaction between ambient PM_{2.5} and different household fuel uses has been attempted to a lesser extent in the previous epidemiological studies. To address these knowledge gaps, this study aimed to investigate whether higher hypertension prevalence or blood pressure was associated with less clean household fuel usage for cooking and heating in a large sample of Chinese adults. In addition, whether these associations were modified by ambient PM_{2.5} exposure was also examined.

METHODS

Study Subject and Design

Participants of this report are part of the Prospective Urban and Rural Epidemiology (PURE) study, who were recruited as the baseline in China during 2005–2009 via a three-level cluster sampling approach (center, community, and household) [18]. PURE-China included a total of 47,677 subjects from

115 communities in 12 centers (i.e., Yunnan, Qinghai, Beijing etc.), and the selection of communities was based on the feasibility for long-term follow-up of study participants with less residential mobility (i.e., living in their current home for a further 4 years) [19]. A total of 2,815 participants were excluded due to missing information on household fuel use for cooking or heating, diagnostic status of hypertension, and age at the time of recruitment. Finally, 44,862 eligible participants were retained in the analysis. The PURE-China study was approved by an institutional ethics review committee and the written informed consent was obtained from each participant before the fieldwork was initiated.

Procedures and Data Collection

Trained research staff conducted face to face interviews using standard questionnaires and a physical examination was performed on each eligible participant. Briefly, we invited each participant to complete a standard questionnaire including information on socio-demographic level (age, sex, location, center, occupation, education attainment, and household possession), lifestyle behavior factors (smoking and alcohol status, secondhand smoke exposure, physical activity, and dietary energy intake), medical history, anti-hypertensive drug, and household fuel use for primary cooking or heating fuel. The physical examination included anthropometric measures (weight, height) and resting blood pressure measurement (sitting) according to standard protocols. The location of each participant's residence was defined as rural or urban according to geographical location. The community is defined as a group of people who have common characteristics and reside in a defined geographical area. Rural communities represent villages more than 50 km away from urban communities or without easy access to commuter transportation [20, 21]. Centers refer to a province of China, so this study has 12 centers. Education attainment was categorized as high (trade school, college or university), middle (secondary or high school), or low (primary or no education). An ever cigarette smoker or alcohol drinker was defined as an individual who was currently using or had ever used any tobacco or alcohol products at the time of interview, otherwise, they were classified as a non-smoker or non-alcohol drinker [22, 23]. Secondhand smoke exposure was defined if an individual had ever lived or worked with at least one smoker and it was categorized as yes or no. Physical activity was assessed using the International Physical Activity Questionnaire and was categorized as low (<600 MET-minutes per week), moderate (600–3000 MET-minutes per week), and high (≥3000 MET-minutes per week). Body mass index (BMI) was calculated by body weight (kilogram) divided by the square of the body height and then it was further categorized as underweight (BMI<18.5), normal (18.5≤BMI<24), overweight (24≤BMI<28), and obese (BMI≥28) [24]. Daily energy intake was assessed using a validated Food Frequency Questionnaire [25]. Household wealth index was calculated according to household possession consisting of 14 assets, which could partly reflect household wealth status. Principal components analysis was then performed to identify the factor with the largest Eigen value, and the factor loading (ranging from –2.25 to 1.75) was treated as

weight for each manifest variable when calculating the household wealth index [26]. Each participant's medical history referred to those who had ever been diagnosed as any of the following diseases: diabetes, stroke, heart failure, other heart diseases, or cancer. History of anti-hypertensive drug treatment was acquired from all participants and it was categorized as "received" and "never received."

Annual PM_{2.5} concentrations were estimated based on satellite and fixed monitoring data by using a geographically weighted regression model with a resolution of 1 km*1 km. To estimate aerosol optical depth, multiple satellite products were analyzed and combined with data from the Sun Photometer and GEOS-Chem simulations [8]. These estimates were used to predict ground-level annual PM_{2.5} concentrations for each community of PURE study. All people living in the same community were assigned the same concentration of PM_{2.5} [27].

Outcome Assessment of Hypertension

We adopted a standard and calibrated digital blood pressure measuring device (Omron HEM-757; Omron Healthcare Co. Ltd., Scarborough, Ontario, Canada) with a cuff size of 14 × 48 cm supplied to measure sitting blood pressure twice separately on the participant's right arm 1 min apart [28, 29]. We took the average value of two separate measurements of systolic blood pressure (SBP) and diastolic blood pressure (DBP) for further analysis. Participants were asked to take at least 5 min to rest and wait 30 min after smoking, exercising, eating, or climbing stairs before measuring blood pressure [18, 30]. A participant was defined as having hypertension if their mean value of SBP ≥ 140 mmHg or DBP ≥ 90 mmHg was obtained at the baseline survey, they were receiving anti-hypertensive drug treatment, or they self-reported hypertension or a physician diagnosed hypertension.

Exposure Assessment of Household Fuel Uses

Information of primary household fuel use was collected at the household level using a standard questionnaire, and participants from the same household were assumed to use the same fuel for cooking and heating. Detailed methods of data collection of primary household fuel use were reported previously [20]. Briefly, we collected information of primary types of household fuel use for cooking and heating via face-to-face interviews. We classified them as 4 major types of utility according to their ranking in energy efficiency classified from the lowest to the highest class of cleanliness determined by their potential emission amount of particulate matters from the combustion process [31]. Electricity does not involve combustion at the household level, it was regarded as the stringent clean fuel and thus was ranked in the highest class of cleanliness on the energy ladder. Combustion of solid fuel emits the highest amounts of particulate matters and thus was ranked as the fuel with the lowest efficiency and the lowest class of cleanliness on the energy ladder, followed by the middle and relatively higher efficient energy sources, i.e., liquid fuel and gas fuel.

We adopted the following steps to regroup types of household fuel utility for cooking or heating based on the cleanliness level of fuel. Step 1, we classified specific types of fuel use for cooking and heating as electricity only (stringent clean energy), gas (gas or gohar gas), liquid (kerosene), and solid (harcoal, coal, wood, agriculture straw, animal dung, and shrub). Step 2, we further categorized portable heaters into liquid as these mainly use kerosene, and open fires into solid as their main sources were coal, wood, or agriculture as heating fuel. We combined central heating with electricity, as central heating is facilitated via transporting heating from other places through a central pipeline without involving any combustion and thus it is also regarded as the stringent clean fuel as well. We also combined participants without fuel use for heating into the electricity category for heating, as they did not use any method that involved combustion and no emission of PM_{2.5} was generated. Step 3, we defined a clean group for household fuel use if electricity was adopted for both the cooking and heating processes. The gas fuel group for household fuel use referred to participants used gas for cooking or heating but did not involve a lower class energy source (i.e., liquid or solid fuel). The classification of the liquid fuel group only counted the use of liquid fuel for either cooking or heating, but did not involve the lowest class energy source (i.e., solid fuel). Solid fuel group referred to participants who adopted solid fuel for either cooking or heating fuel regardless of whether a higher class fuel type in energy ladder was also used.

Statistical Analysis

We reported categorical variables as frequency and proportion, while continuous variables were described as mean and standard deviation (SD) for normal distribution and median (and interval of quantile range, IQR) for skewed distribution. The association between primary household fuel usage by energy cleanliness and hypertension prevalence were examined using a multilevel logistic regression model after taking the center as a random effect to deal with the potential clustering effect of participants within the centers. Base model was adjusted for age, sex, and location, the full model was further controlled for smoking status, secondhand smoke exposure, drinking status, education level, occupational class, household wealth index, BMI status, physical activity, energy intake, and ambient PM_{2.5} concentration. We investigated the associations between types of primary household fuel use and blood pressure by using a generalized linear mixed model with random intercepts to account for clustering by centers. The base model for blood pressure was the same as that of hypertension, and the full model was also same as that of hypertension but further adjusted for anti-hypertensive drug treatment and medical history.

We explored the association between primary types of household fuel uses and hypertension prevalence or blood pressure according to ambient PM_{2.5} exposure (high and low, categorized by median value) and location of residence (urban or rural) to understand the potential interaction. Furthermore, an interaction term (household fuel use × anti-hypertensive drug treatment) was introduced into the full model and sensitivity analyses were also performed among participants with and

TABLE 1 | Basic characteristics of the 44,862 study participants by primary household fuel use (Prospective Urban and Rural Epidemiology study in China, 2005–2009).

	All participants	Solid	Liquid	Gas	Electricity
No. (%)	44,862 (100)	25,336 (56.5)	974 (2.2)	17,534 (39.1)	1,018 (2.3)
Age, mean \pm SD, y	51.1 \pm 9.65	50.1 \pm 9.48	53.3 \pm 9.65	52.4 \pm 9.68	51.5 \pm 9.87
Female (n, %)	26,200 (58.4)	14,435 (57)	588 (60.4)	10,573 (60.3)	604 (59.3)
Socioeconomic status					
Rural (n, %)	22,776 (50.8)	20,212 (79.8)	189 (19.4)	2,199 (12.5)	176 (17.3)
Education attainment					
Primary (n, %)	15,204 (34)	11,312 (44.8)	206 (21.2)	3,262 (18.7)	424 (41.7)
Secondary (n, %)	22,916 (51.2)	11,962 (47.3)	552 (56.7)	9,955 (56.9)	447 (44)
College/University (n, %)	6,620 (14.8)	1,993 (7.9)	215 (22.1)	4,267 (24.4)	145 (14.3)
Household wealth index (n, %)					
Lower	14,799 (33)	12,714 (50.2)	114 (11.7)	1,722 (9.8)	249 (24.5)
Middle	15,190 (33.9)	8,001 (31.6)	363 (37.3)	6,452 (36.8)	374 (36.7)
Higher	14,872 (33.2)	4,620 (18.2)	497 (51)	9,360 (53.4)	395 (38.8)
Unhealthy lifestyle habits					
Ever smoking (n, %)	12,079 (27.4)	7,092 (28.5)	219 (22.9)	4,488 (25.9)	280 (28.2)
Secondhand smoke exposure (n, %)	13,055 (38.8)	7,261 (39.1)	254 (32.7)	5,281 (39)	259 (33.9)
Ever alcohol drinking (n, %)	10,835 (24.4)	6,349 (25.4)	210 (21.7)	4,003 (23)	273 (27.4)
Physical activity (MET score)					
Low (<600) (n, %)	7,467 (16.6)	4,692 (18.5)	239 (24.5)	2,306 (13.2)	230 (22.6)
Moderate (600 to <3,000) (n, %)	18,705 (41.7)	10,541 (41.6)	459 (47.1)	7,302 (41.6)	403 (39.6)
High (\geq 3,000) (n, %)	18,690 (41.7)	10,103 (39.9)	276 (28.3)	7,926 (45.2)	385 (37.8)
Energy intake (n, %)					
Lower	15,915 (35.5)	8,381 (33.1)	430 (44.1)	6,835 (39)	269 (26.4)
Middle	14,389 (32.1)	8,112 (32)	287 (29.5)	5,630 (32.1)	360 (35.4)
Higher	14,558 (32.5)	8,843 (34.9)	257 (26.4)	5,069 (28.9)	389 (38.2)
Physical measurement					
BMI, mean \pm SD, kg/m ²	24.6 \pm 3.66	24.5 \pm 3.74	24.6 \pm 3.56	24.7 \pm 3.56	24.8 \pm 3.45
Underweight (n, %)	1,488 (3.3)	932 (3.7)	33 (3.4)	495 (2.8)	28 (2.8)
Normal weight (n, %)	19,518 (43.5)	11,386 (44.9)	414 (42.5)	7,306 (41.7)	412 (40.5)
Overweight (n, %)	16,741 (37.3)	8,974 (35.4)	373 (38.3)	6,984 (39.8)	410 (40.3)
Obese (n, %)	7,115 (15.9)	4,044 (16)	154 (15.8)	2,749 (15.7)	168 (16.5)
SBP, mean \pm SD, mmHg	133.6 \pm 22.42	135.6 \pm 22.61	128.7 \pm 21.48	131.4 \pm 21.94	129.2 \pm 21.71
DBP, mean \pm SD, mmHg	82.9 \pm 13.21	83.8 \pm 13.7	80.6 \pm 12.08	81.7 \pm 12.45	80.7 \pm 12.61
Other exposures					
Medical history	3,813 (8.5)	1,711 (6.8)	97 (10)	1,915 (10.9)	90 (8.8)
With anti-hypertension medicine (n, %)	6,023 (13.4)	2,766 (10.9)	169 (17.4)	2,968 (16.9)	120 (11.8)
Ambient PM _{2.5} , median, IQR, ug/m ³	45.8 (39.9)	45.8 (51.3)	49.2 (25.4)	43.8 (24.2)	53.9 (34.2)

BMI, body mass index; SD, standard deviation; IQR, interquartile range; SBP, systolic blood pressure; DBP, diastolic blood pressure. Underweight: BMI<18.5, Normal: 18.5≤BMI<24, Overweight: 24≤BMI<28, Obese: BMI≥28.

without receiving any anti-hypertensive drug treatment to see if the association between household fuel use and blood pressure was robust. All of the statistical analysis was conducted by SAS® software (version 9.4) with a significance level of 0.05 using two-sided test.

RESULTS

A total of 44,862 eligible participants were included in this report, with a mean age of 51.1 years old (SD = 9.7) and women making up 58.4%. The annual median concentration of ambient PM_{2.5} was 45.8 ug/m³, and 50.8% of the participants inhabited a rural area. 25,336 (56.5%) of the participants were classified into the solid fuel use group, while 974 (2.2%) and 17,534 (39.1%) were classified as the liquid fuel use and gas fuel use group for either cooking or heating, respectively. There were 685 participants using electricity as the primary household fuel for both heating and cooking.

Table 1 summarizes the distribution of basic characteristics of 44,862 participants using different household fuel types according to the cleanliness of fuel. Among all primary types of fuel users, participants who adopted solid fuel as their primary source for heating or cooking were more likely to inhabit a rural area, have a lower household wealth index value, consume higher amounts of energy, be in the normal weight category, and have relatively higher SBP or DBP. Participants in the liquid fuel use subgroup had relatively lower SBP and DBP. More participants in the gas fuel use subgroup received high education, had a higher wealth index value, and were more prone to be exposed to lower ambient PM_{2.5}, however, participants in the electricity subgroup were more prone to be exposed to higher ambient PM_{2.5}, alcohol consumption, and were more likely to be overweight or obese.

Table 2 compares the associations of hypertension prevalence and blood pressure with different household fuel uses for cooking or heating based on the cleanliness level of fuel. Using the least clean “solid fuel” as the reference, participants who adopted cleaner fuels (i.e., gas and electricity) were associated with

TABLE 2 | Associations of household fuels according to cleanliness ranking on the energy ladder with hypertension prevalence and blood pressure (Prospective Urban and Rural Epidemiology study in China, 2005–2009).

Fuel uses	No. of hypertension	Prevalence crude rate (95%CI)	Hypertension (AOR, 95% CI)		Systolic blood pressure (mmHg, 95% CI)		Diastolic blood pressure (mmHg, 95% CI)	
			Model 1 ^a	Model 2 ^b	Model 1 ^a	Model 2 ^c	Model 1 ^a	Model 2 ^c
Solid	10,902 (58.1)	43.0 (42.42, 43.64)	1.00	1.00	Ref	Ref		
Liquid	376 (2.00)	38.6 (35.55, 41.66)	0.97 (0.84, 1.12)	0.95 (0.78, 1.15)	-2.68 (-4.07, -1.28)	-2.83 (-4.46, -1.20)	-0.24 (-1.12, 0.63)	-0.87 (-1.82, 0.08)
Gas	7,114 (37.9)	40.6 (39.85, 41.30)	0.97 (0.91, 1.03)	0.91 (0.83, 0.99)	-1.57 (-2.15, -0.98)	-2.40 (-3.10, -1.71)	-0.03 (-0.39, 0.34)	-0.52 (-0.94, -0.09)
Electricity	372 (2.00)	36.5 (33.58, 39.50)	0.80 (0.69, 0.92)	0.72 (0.60, 0.87)	-3.42 (-4.79, -2.04)	-5.26 (-6.84, -3.67)	-1.99 (-2.85, -1.13)	-2.35 (-3.32, -1.38)
<i>p</i> value (for trend)			0.04	<0.01	<0.01	<0.01	0.09	<0.01

^aModel 1 adjusted for age, sex, location, and random effect for center.

^bModel 2 adjusted for age, sex, location, smoking status, secondhand smoke exposure, drinking status, education level, occupational class, household wealth index, BMI status, physical activity, energy intake, ambient PM2.5 concentration, and random effect for center.

^cModel 2 adjusted for age, sex, location, smoking status, secondhand smoke exposure, drinking status, education level, occupational class, household wealth index, BMI status, physical activity, energy intake, personal medical history, ambient PM2.5 concentration, taking hypertension medicine, and random effect for center.

TABLE 3 | The association between hypertension prevalence/blood pressure and energy ladder, stratified by ambient Particulate Matter 2.5^a (Prospective Urban and Rural Epidemiology study in China, 2005–2009).

Fuel type	Low ambient PM2.5 (N = 24,115)				High ambient PM2.5 (N = 20,747)			
	No. of hypertension	AOR ^b (95% CI)	SBP ^c (mmHg, 95% CI)	DBP ^c (mmHg, 95% CI)	No. of hypertension	AOR ^b (95% CI)	SBP ^c (mmHg, 95% CI)	DBP ^c (mmHg, 95% CI)
Solid	5,354 (40.5)	1.00		Ref	5,548 (45.8)	1.00		Ref
Liquid	205 (36.4)	0.95 (0.75, 1.22)	-1.18 (-3.15, 0.78)	-0.37 (-1.62, 0.88)	171 (41.6)	0.84 (0.65, 1.09)	-4.97 (-7.31, -2.64)	-1.83 (-3.32, -0.34)
Gas	4,104 (40.4)	0.99 (0.88, 1.10)	-1.10 (-2.01, -0.19)	-0.51 (-1.10, 0.07)	3,010 (40.8)	0.85 (0.76, 0.95)	-2.86 (-3.85, -1.87)	-0.62 (-1.25, -0.01)
Electricity	56 (31.8)	0.95 (0.61, 1.46)	1.45 (-2.02, 4.92)	0.22 (-1.99, 2.43)	316 (37.5)	0.71 (0.58, 0.87)	-6.08 (-7.86, -4.31)	-2.62 (-3.75, -1.49)
<i>p</i> value (for trend)		0.99	0.05	0.12		<0.01	<0.01	<0.01

^aLow and high ambient PM2.5 was classified by median value (50.8 ug/m³).

^bModel adjusted for age, sex, location, smoking status, secondhand smoke exposure, drinking status, education level, occupational class, household wealth index, BMI status, physical activity, energy intake, and random effect for center.

^cModel adjusted for age, sex, location, smoking status, secondhand smoke exposure, drinking status, education level, occupational class, household wealth index, BMI status, physical activity, energy intake, personal medical history, taking hypertension medicine, and random effect for center.

SBP, systolic blood pressure; DBP, diastolic blood pressure.

significantly lower hypertension prevalence after a full adjustment of a variety of confounding factors, except for the household liquid fuel users. Utilizing higher class energy efficient fuel types tended to be associated with a lower risk of SBP or DBP, with the most prominent effect for participants using electricity as the primary household fuel.

Table 3 presents the association between hypertension prevalence, blood pressure, and primary fuel use in both the high and low ambient PM2.5 exposure groups. A significant interaction was observed between household fuel use and ambient PM2.5 exposure on the effect of SBP ($p < 0.001$) or DBP ($p = 0.02$). Among the subgroup with high ambient PM2.5 exposure, compared with the solid fuel subgroup,

participants using a cleaner fuel tended to be associated with lower risk of hypertension and blood pressure, specifically for the electricity group (AOR = 0.71, 95% CI: 0.58, 0.87; SBP = -6.08, 95%CI: -7.86, -4.31; DBP = -2.62, 95% CI: -3.75, -1.49). In the low ambient PM2.5 exposure group, a significantly lower odds with blood pressure was only observed among those utilizing gas as the primary fuel. The pattern of association among participants inhabiting urban and rural areas was similar to those with high and low ambient PM2.5 exposure, respectively (**Table 4**). The association was more significant in the urban subgroup.

Sensitivity analyses revealed that participants not receiving anti-hypertensive drug treatment showed a significantly lower

TABLE 4 | The association between hypertension prevalence/blood pressure and energy ladder, stratified by location (Prospective Urban and Rural Epidemiology study in China, 2005–2009).

Fuel type	Rural areas (N = 22,776)				Urban areas (N = 22,086)			
	No. of hypertension	AOR ^a (95% CI)	SBP ^b (mmHg, 95% CI)	DBP ^b (mmHg, 95% CI)	No. of hypertension	AOR ^a (95% CI)	SBP ^b (mmHg, 95% CI)	DBP ^b (mmHg, 95% CI)
Solid	8,574 (42.4)	1.00		Ref	2,328 (45.4)	1.00		Ref
Liquid	71 (38.1)	0.78 (0.52, 1.16)	-2.29 (-5.64, 1.07)	-0.66 (-2.86, 1.54)	304 (38.7)	0.94 (0.75, 1.18)	-2.69 (-4.62, -0.77)	-0.67 (-1.86, 0.53)
Gas	803 (36.5)	0.87 (0.75, 1.00)	-0.45 (-1.74, 0.84)	-0.22 (-1.06, 0.63)	6,311 (41.2)	0.94 (0.84, 1.05)	-2.45 (-3.38, -1.52)	-0.91 (-1.49, -0.34)
Electricity	77 (43.8)	0.97 (0.64, 1.47)	-3.25 (-6.85, 0.36)	0.57 (-1.79, 2.94)	295 (35.0)	0.78 (0.63, 0.98)	-2.86 (-4.70, -1.02)	-2.23 (-3.38, -1.09)
p value (for trend)		0.06	0.13	0.78		0.08	<0.01	<0.01

^aModel adjusted for age, sex, smoking status, secondhand smoke exposure, drinking status, education level, occupational class, household wealth index, BMI status, physical activity, energy intake, ambient PM2.5 concentration, and random effect for center.

^bModel adjusted for age, sex, smoking status, secondhand smoke exposure, drinking status, education level, occupational class, household wealth index, BMI status, physical activity, energy intake, personal medical history, ambient PM2.5 concentration, taking hypertension medicine, and random effect for center. SBP, systolic blood pressure; DBP, Diastolic blood pressure.

TABLE 5 | The association between blood pressure and energy ladder, stratified by anti-hypertension medicine^a (Prospective Urban and Rural Epidemiology study in China, 2005–2009).

Fuel type	Without anti-hypertension medicine (N = 38,839)			With anti-hypertension medicine (N = 6,023)		
	No. of hypertension	SBP (mmHg, 95% CI)	DBP (mmHg, 95% CI)	No. of hypertension	SBP (mmHg, 95% CI)	DBP (mmHg, 95% CI)
Solid	8,184 (36.3)		Ref	2,718 (98.3)		Ref
Liquid	209 (26.0)	-3.09 (-4.68, -1.50)	-0.56 (-1.58, 0.47)	167 (98.8)	-6.94 (-11.1, -2.82)	-3.16 (-5.60, -0.71)
Gas	4,186 (28.7)	-2.46 (-3.15, -1.76)	-0.46 (-0.91, -0.01)	2,928 (98.7)	-1.40 (-3.40, 0.60)	-1.08 (-2.26, 0.11)
Electricity	253 (28.2)	-5.45 (-7.05, -3.86)	-2.55 (-3.58, -1.52)	119 (99.2)	-1.35 (-5.96, 3.27)	-1.86 (-4.58, 0.89)
p value (for trend)		<0.01	<0.01		0.40	0.10

^aModel adjusted for age, sex, location, smoking status, secondhand smoke exposure, drinking status, education level, occupational class, household wealth index, BMI status, physical activity, energy intake, personal medical history, ambient PM2.5 concentration, and random effect for center.

SBP, systolic blood pressure; DBP, diastolic blood pressure.

trend for the association of blood pressure with the rising cleanliness ranking of fuel types, and a significant interaction between household fuel use and anti-hypertensive medication was suggested for the risk of blood pressure ($p < 0.001$) (Table 5).

DISCUSSION

This was a population-based multi-center study demonstrating that utilizing cleaner household fuel was associated with lower prevalence of hypertension and a lower level of blood pressure. Electricity is the stringent clean fuel source as it does not involve a combustion process or emission of particulate matters. Compared with the least clean solid fuel, participants using electricity fuel for household cooking and heating had relatively lower risks of hypertension prevalence and a lower level of blood pressure than those using the liquid or gas fuel, and the findings were more prominent among participants not receiving anti-hypertensive medications, despite a consistent pattern that was also observed among those receiving anti-hypertensive drug treatment. A consistently decreasing trend

for the association between hypertension or blood pressure and the rising cleanliness of household fuel was demonstrated among participants exposed to a relatively high ambient PM2.5 concentration and those inhabiting urban areas where the outdoor air population was also high, and these novel findings have never been reported in previous studies.

Except for this PURE-China study, only a few epidemiological studies investigated the association between household fuel use and hypertension prevalence in China [22, 23, 32–34]. A hospital-based study containing 14,068 adults in Shanghai of China showed a significantly increased risk of hypertension (OR = 1.70, 95% CI = 1.40, 2.07) among ever solid fuel users [32]. Another study including 9 regions of China with 4,594 participants also reported a similar finding that indoor air pollution emitted from using household solid fuel for cooking or heating was significantly associated with hypertension prevalence (OR = 1.11, 95% CI = 1.11, 1.12) [33]. Deng et al reported that biomass fuel for cooking was associated with a slightly higher risk of hypertension based on 3,754 older Chinese adults [23]. In addition, a study of 8,067 elderly participants over 65 years in China showed that people using solid fuel for cooking

may be at a higher risk of elevated blood pressure than those using clean fuel, but no association between solid fuel use and hypertension was observed [22]. However, these previous studies only took cooking fuel into account, without considering heating fuel. A recent study demonstrated that indoor solid fuel use for heating was associated with increases in SBP or DBP levels and increased risk of hypertension, but no significant association was observed between indoor fuel use for cooking and hypertension or blood pressure [8]. Overall, a literature review showed that none of the previous studies provided evidence on the association with other major types of household fuel use according to the level of cleanliness, and the residual confounding effect is still a concern. Compared with the previous studies, our study addressed more potential confounding factors, such as education level, occupational class, secondhand smoke exposure, energy intake, and ambient PM2.5 concentration. A global study analyzed 12 Demographic and Health Surveys (DHS) from 10 countries (i.e., Albania, Armenia, Azerbaijan, Bangladesh, Benin, Ghana, Kyrgyzstan, Lesotho, Namibia, and Peru), by using clean cooking fuel (including gas) as the reference group, they found that using household solid fuel was not significantly associated with hypertension prevalence (OR = 1.07, 95%CI = 0.99, 1.16) [10]. Our study used the solid fuel as the comparison and revealed a significantly lower odds between using electricity as household fuel and hypertension prevalence (AOR = 0.72, 95% = 0.60, 0.87), as well as a significantly lower level of SBP by 5.26 mmHg and DBP by 1.99 mmHg. Gas was regarded as a clean fuel in many previous studies when comparing the health outcomes with household solid fuel use [20, 35]; however, field measurement results indicated that gas during the combustion process could still increase the concentrations of several hazardous chemical pollutants including Carbonic oxide, PM2.5, nitric oxide, and nitrogen dioxide [36]. Our analysis also found significantly lower odds of hypertension of 0.91 and a significantly lower level of SBP or DBP by 2.40 mmHg or 0.52 mmHg for participants using gas as their primary household fuel for cooking and heating; nevertheless, these risks were still about 5%–28% higher than for those using electricity as the primary household fuel. Therefore, evidence from our study highlights that using household gas fuel as the benchmark of clean fuel may lead to an underestimation of the actual effect of other types of household fuel on the risk of hypertension or blood pressure in the previous studies [37].

Few of the previous epidemiological studies compared the effect of specific fuel type classified based on cleanliness and fuel efficiency on the risk of hypertension and blood pressure levels between groups with high and low ambient PM2.5 exposure. Our study demonstrated significantly lower odds between using cleaner household fuels and hypertension or a lower blood pressure level in participants with high ambient PM2.5 exposure, with the lowest association among those utilizing electricity as the primary household fuel for cooking and heating. A similar pattern was also suggested among people inhabiting urban areas in which the air pollution level was higher than the rural areas. Long-term exposure to ambient

PM2.5 may increase blood C-reactive protein and oxidative stress, causing systemic inflammation, which in turn may lead to atherosclerosis and adversely alter vascular functions [38]. Such chronic systemic inflammation in the circulation system may be exaggerated by further exposure to indoor PM2.5 emitted from combustion of household fuels for cooking and heating, and this biological mechanism reasonably explains the observed lower odds of hypertension or lower blood pressure levels with increasing cleanliness of the household fuel.

Strengths and Limitations

The strengths of this study include it being a global standardized study design with good quality control, large sample size, good representation of participants with diverse social economic backgrounds, and standardized approaches to data collection via a detailed questionnaire. Importantly, this is the first Chinese study characterizing the health effects of household air pollution derived from fuel usage based on order of cleanliness, and thus is the first to present the scientific evidence that moving up the energy ladder is associated with lower hypertension prevalence and blood pressure level in Chinese adults. Moreover, we applied random effect into the model which fully considered the heterogeneities between centers. However, limitations of this study should be mentioned. First, information on the primary cooking and heating source were acquired using self-reported questionnaires which is not an objective measurement and may only reflect the participants' adoption during baseline survey. Second, the inclusion of people receiving antihypertensive medication in the analysis may potentially introduce a risk of selection bias, because their blood pressures were under control. We conducted sensitivity analyses according to participants' statuses on receiving antihypertensive medications and the findings were robust. Third, we did not include season in the final model, however, as season is correlated with the heating provision period, including season in the model may seriously underestimate the risk estimate of interest related to household fuel use for heating. Concerns may also arise from a relatively small group using electricity or liquid (kerosene) particularly when further subgroup analyses by ambient PM2.5 and location were performed, which might yield the effect to be measured in an unstable way. This limitation along with the nature of cross-sectional study of the baseline survey made the cause-effect difficult to determine, and thus the associations would have to be confirmed by prospective cohort studies involving repeated measurement of blood pressure and hypertension during the follow-up. Given the actual pattern of ambient PM2.5 exposure level in mainland China, we used the median ambient PM2.5 concentration of 45.8 $\mu\text{g}/\text{m}^3$ rather than WHO's annual standard as the cut-off to group the high and low exposure groups to keep a reasonable sample size and power in the subgroup analysis. Lastly, while the baseline data were collected during 2005–2009, the results are still relevant to some remote rural areas in China and the developing countries in which the unclean fuels are still being used.

Conclusion

In conclusion, this study uniquely provides evidence that utilizing cleaner types of household fuel is associated with lower hypertension prevalence and a lower level of blood pressure in Chinese adults, with a more pronounced association among people with high ambient PM_{2.5} exposure. Electricity, ranked as the cleanest fuel type, was associated with the lowest hypertension prevalence and the lowest level of blood pressure compared with the uses of other household fuel types. Gas, ranked as a highly clean level on the energy ladder, was also associated with lower hypertension prevalence and lower blood pressure values, but the effect was weaker than that of the household electricity users for cooking and heating. Our study urges the promotion of cleaner household fuel usage to reduce the burden of hypertension and therefore the subsequent complications induced by hypertension.

DATA AVAILABILITY STATEMENT

The datasets analysed during the current study are not publicly available due to an ongoing project, but are available from the corresponding author on reasonable request.

ETHICS STATEMENT

The project of “The Prospective Urban and Rural Health Evaluation Study: PURE” is a global study (baseline), which was approved on both ethical and scientific grounds by McMaster University Research Ethics Board on 7 July 2003, the approval number is 03-206. The PURE-China (baseline) was approved by the Medical Research Ethics Committee of Fuwai Hospital and The Chinese Academy of Medical Sciences on 24 March 2005. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ZGL and MYL: Design and interpretation of this study, analysis of data, drafting and revising the manuscript. PH: Revising the manuscript and giving comments. YBZ: Drafting and revising the manuscript. SR: Coordinated the study. YTM, QZ, and LHH: Acquisition data and quality control. SY: Designed the study and revising the manuscript. YL: Conceiving the analysis and drafting the final manuscript. LAT: Raise hypothesis of the manuscript, drafted and revised the manuscript, and academic supervisory.

FUNDING

The PURE study is an investigator-initiated study that is funded by the Population Health Research Institute (PHRI), Hamilton Health Sciences Research Institute (HHSRI), the Canadian Institutes of Health Research, Heart

and Stroke Foundation of Ontario. The PURE-AIR study is funded by Canadian Institutes for Health Research (CIHR; grant 136893) and by the Office of the Director, National Institutes of Health (NIH; award DP5OD019850). Funding was also provided by unrestricted grants from AstraZeneca (Canada), Sanofi-Aventis (France and Canada), Boehringer Ingelheim (Germany and Canada), Servier, and GlaxoSmithKline and additional contributions from Novartis and King Pharma and from various national or local organizations in participating countries which are listed below. The funder was not involved in the study design, collection, analysis, interpretation of data, the writing of this article, or the decision to submit it for publication. PURE-China study is partly funded by the National Center for Cardiovascular Diseases, ThinkTank Research Center for Health Development, and the National Clinical Research Center for Cardiovascular Diseases, Fwui Hospital, Chinese Academy of Medical Sciences (NCRC2020002).

National and local funding organizations: Argentina: Fundacion ECLA (Estudios Clinicos Latino America); Bangladesh: Independent University, Bangladesh and Mitra and Associates; Brazil: Unilever Health Institute, Brazil; Canada: Public Health Agency of Canada and Champlain Cardiovascular Disease Prevention Network; Chile: Universidad de la Frontera; China: National Center for Cardiovascular Diseases and ThinkTank Research Center for Health Development; Colombia: Colciencias (grant 6566-04-18062 and grant 6517-777-58228); India: Indian Council of Medical Research; Malaysia: Ministry of Science, Technology and Innovation of Malaysia (grant number: 100-IRDC/BIOTEK 16/6/21 [13/2007], and 07-05-IFN-BPH 010), Ministry of Higher Education of Malaysia (grant number: 600-RMI/LRGS/5/3 [2/2011]), Universiti Teknologi MARA, Universiti Kebangsaan Malaysia (UKM-Hejira-Komuniti-15-2010); occupied Palestinian territory: the United Nations Relief and Works Agency for Palestine Refugees in the Near East, occupied Palestinian territory; International Development Research Centre, Canada; Philippines: Philippine Council for Health Research and Development; Poland: Polish Ministry of Science and Higher Education (grant number: 290/W-PURE/2008/0), Wroclaw Medical University; Saudi Arabia: Saudi Heart Association, Saudi Gastroenterology Association, Dr. Mohammad AlFagih Hospital, The Deanship of Scientific Research at King Saud University, Riyadh, Saudi Arabia (Research group number: RG -1436-013); South Africa: The North-West University, SA and Netherlands Programme for Alternative Development, National Research Foundation, Medical Research Council of South Africa, The South Africa Sugar Association, Faculty of Community and Health Sciences; Sweden: Grants from the Swedish state under the Agreement concerning research and education of doctors; the Swedish Heart and Lung Foundation; the Swedish Research Council; the Swedish Council for Health, Working Life and Welfare, King Gustaf V:s and Queen Victoria Freemason's Foundation, AFA Insurance; Turkey: Metabolic Syndrome Society, AstraZeneca, Sanofi Aventis; United Arab Emirates: Sheikh Hamdan Bin Rashid Al Maktoum Award for Medical Sciences and Dubai Health Authority.

CONFLICT OF INTEREST

The authors declare that they do not have any conflicts of interest.

ACKNOWLEDGMENTS

PURE-China Project Office Staff, National Coordinators, Investigators: Liu Lisheng, Li Wei, Hu Bo, Zhu Jun, Han

REFERENCES

- Cesaroni G, Badaloni C, Gariazzo C, Stafoggia M, Sozzi R, Davoli M, et al. Long-term Exposure to Urban Air Pollution and Mortality in a Cohort of More Than a Million Adults in Rome. *Environ Health Perspect* (2013) 121(3): 324–31. doi:10.1289/ehp.1205862
- Pope CA, Turner MC, Burnett RT, Jerrett M, Gapstur SM, Diver WR, et al. Relationships between fine Particulate Air Pollution, Cardiometabolic Disorders, and Cardiovascular Mortality. *Circ Res* (2015) 116(1):108–15. doi:10.1161/CIRCRESAHA.116.305060
- Hales S, Blakely T, Woodward A. Air Pollution and Mortality in New Zealand: Cohort Study. *J Epidemiol Community Health* (2012) 66(5):468–73. doi:10.1136/jech.2010.112490
- Burroughs Peña M, Romero KM, Velazquez EJ, Davila-Roman VG, Gilman RH, Wise RA, et al. Relationship between Daily Exposure to Biomass Fuel Smoke and Blood Pressure in High-Altitude Peru. *Hypertension* (2015) 65(5):1134–40. doi:10.1161/HYPERTENSIONAHA.114.04840
- Cao X, Tang H, Zheng C, Kang Y, Zhang L, Wang X, et al. Association of Heating Fuel Types with Mortality and Cardiovascular Events Among Non-smokers in China. *Environ Pollut* (2021) 291:118207. doi:10.1016/j.envpol.2021.118207
- Nadadur SS, Hollingsworth JW. *Air Pollution and Health Effects*. Springer (2015).
- Tielsch JM, Katz J, Zeger SL, Khattry SK, Shrestha L, Breysse P, et al. Designs of Two Randomized, Community-Based Trials to Assess the Impact of Alternative Cookstove Installation on Respiratory Illness Among Young Children and Reproductive Outcomes in Rural Nepal. *BMC Public Health* (2014) 14(1):1271. doi:10.1186/1471-2458-14-1271
- Lin L, Wang HH, Liu Y, Lu C, Chen W, Guo VY. Indoor Solid Fuel Use for Heating and Cooking with Blood Pressure and Hypertension: A Cross-Sectional Study Among Middle-Aged and Older Adults in China. *Indoor Air* (2021) 31(6):2158–66. doi:10.1111/ina.12872
- Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, et al. A Comparative Risk Assessment of burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990–2010: a Systematic Analysis for the Global Burden of Disease Study 2010. *Lancet* (2012) 380(9859):2224–60. doi:10.1016/S0140-6736(12)61766-8
- Arku RE, Ezzati M, Baumgartner J, Fink G, Zhou B, Hystad P, et al. Elevated Blood Pressure and Household Solid Fuel Use in Premenopausal Women: Analysis of 12 Demographic and Health Surveys (DHS) from 10 Countries. *Environ Res* (2018) 160:499–505. doi:10.1016/j.envres.2017.10.026
- Arku RE, Brauer M, Ahmed SH, AlHabib KF, Avezum Á, Bo J, et al. Long-term Exposure to Outdoor and Household Air Pollution and Blood Pressure in the Prospective Urban and Rural Epidemiological (PURE) Study. *Environ Pollut* (2020) 262:114197. doi:10.1016/j.envpol.2020.114197
- Fatmi Z, Ntani G, Coggon D. Coronary Heart Disease, Hypertension and Use of Biomass Fuel Among Women: Comparative Cross-Sectional Study. *BMJ open* (2019) 9(8):e030881. doi:10.1136/bmjopen-2019-030881
- Shupler M, Hystad P, Birch A, Miller-Lionberg D, Jeronimo M, Arku RE, et al. Household and Personal Air Pollution Exposure Measurements from 120 Communities in Eight Countries: Results from the PURE-AIR Study. *Lancet Planet Health* (2020) 4(10):e451–62. doi:10.1016/S2542-5196(20)30197-2
- Guoliang, Xie Liya, Wang Chuangshi, Liu Zhiguang, Li Mengya, Deng Qing, Liang Yan, Li Yang, Xia Yanjie, Hao Jun, Lang Xinyue, Li Xiacong, Sun Yi, Liu Xiaoyun, Zhang Hongye, Wang Xingyu, Li Sidong, Liu Weida, Wang Yang, Jia Xuan, He Xinye, Cheng Xiaoru, Lu Fanghong, Kai You, Hou Yan, Zhang Liangqing, Guo Baoxia, Liao Xiaoyang, Chen Di, Zhang Peng, Li Ning, Ma Xiaolan, Lei Rensheng, Fu Minfan, Liu Yu, Xing Xiaojie, Ma Yuanting, Guomin He, Xiang Quanyong, Tang Jinhua, Liu Zhengrong, Qiang Deren, Han Aiyang, Aideeraili, Ayoupu, Zhao Qian.
- Li L, Yang A, He X, Liu J, Ma Y, Niu J, et al. Indoor Air Pollution from Solid Fuels and Hypertension: A Systematic Review and Meta-Analysis. *Environ Pollut* (2020) 259:113914. doi:10.1016/j.envpol.2020.113914
- Smith KR, Apte MG, Yuqing M, Wongsekiarttirat W, Kulkarni A. Air Pollution and the Energy Ladder in Asian Cities. *Energy* (1994) 19(5): 587–600. doi:10.1016/0360-5442(94)90054-x
- Wong TW, Wong AHS, Lee FSC, Qiu H. Respiratory Health and Lung Function in Chinese Restaurant Kitchen Workers. *Occup Environ Med* (2011) 68(10):746–52. doi:10.1136/oem.2010.059378
- Kanagasabai T, Xie W, Yan L, Zhao L, Carter E, Guo D, et al. Household Air Pollution and Blood Pressure, Vascular Damage, and Subclinical Indicators of Cardiovascular Disease in Older Chinese Adults. *Am J Hypertens* (2022) 35(2): 121–31. doi:10.1093/ajh/hpab141
- Teo K, Chow CK, Vaz M, Rangarajan S, Yusuf S. The Prospective Urban Rural Epidemiology (PURE) Study: Examining the Impact of Societal Influences on Chronic Noncommunicable Diseases in Low-Middle-And High-Income Countries. *Am Heart J* (2009) 158(1):1–7. doi:10.1016/j.ahj.2009.04.019
- Yusuf S, Islam S, Chow CK, Rangarajan S, Dagenais G, Diaz R, et al. Use of Secondary Prevention Drugs for Cardiovascular Disease in the Community in High-Income, Middle-Income, and Low-Income Countries (The PURE Study): a Prospective Epidemiological Survey. *Lancet* (2011) 378(9798): 1231–43. doi:10.1016/S0140-6736(11)61215-4
- Hystad P, Duong M, Brauer M, Larkin A, Arku R, Kurmi OP, et al. Health Effects of Household Solid Fuel Use: Findings from 11 Countries within the Prospective Urban and Rural Epidemiology Study. *Environ Health Perspect* (2019) 127(5):57003. doi:10.1289/EHP3915
- National Bureau of Statistics. *Provisions on the Statistical Division of Urban and Rural Areas* (1999).
- Yu Q, Zuo G. Relationship of Indoor Solid Fuel Use for Cooking with Blood Pressure and Hypertension Among the Elderly in China. *Environ Sci Pollut Res Int* (2022) 29(35):53444–55. doi:10.1007/s11356-022-19612-1
- Deng Y, Gao Q, Yang D, Hua H, Wang N, Ou F, et al. Association between Biomass Fuel Use and Risk of Hypertension Among Chinese Older People: A Cohort Study. *Environ Int* (2020) 138:105620. doi:10.1016/j.envint.2020.105620
- Obese NWO. Body Mass Index (BMI). *Obes Res* (1998) 6(2):51S–209S.
- Dehghan M, Ilow R, Zatonska K, Szuba A, Zhang X, Mente A, et al. Development, Reproducibility and Validity of the Food Frequency Questionnaire in the Poland Arm of the Prospective Urban and Rural Epidemiological (PURE) Study. *J Hum Nutr Diet* (2012) 25(3):225–32. doi:10.1111/j.1365-277X.2012.01240.x
- Gupta R, Islam S, Mony P, Kutty VR, Mohan V, Kumar R, et al. Socioeconomic Factors and Use of Secondary Preventive Therapies for Cardiovascular Diseases in South Asia: The PURE Study. *Eur J Prev Cardiol* (2015) 22(10): 1261–71. doi:10.1177/2047487314540386
- van Donkelaar A, Martin RV, Brauer M, Hsu NC, Kahn RA, Levy RC, et al. Global Estimates of Fine Particulate Matter Using a Combined Geophysical-Statistical Method with Information from Satellites, Models, and Monitors. *Environ Sci Technol* (2016) 50(7):3762–72. doi:10.1021/acs.est.5b05833
- El Assaad MA, Topouchian JA, Asmar RG. Evaluation of Two Devices for Self-Measurement of Blood Pressure According to the International Protocol: the Omron M5-I and the Omron 705IT. *Blood Press Monit* (2003) 8(3):127–33. doi:10.1097/00126097-200306000-00006
- Omboni S, Riva I, Giglio A, Caldara G, Groppelli A, Parati G. Validation of the Omron M5-I, R5-I and HEM-907 Automated Blood Pressure Monitors in Elderly Individuals

- According to the International Protocol of the European Society of Hypertension. *Blood Press Monit* (2007) 12(4):233–42. doi:10.1097/MBP.0b013e32813fa386
30. Chow CK, Teo KK, Rangarajan S, Islam S, Gupta R, Avezum A, et al. Prevalence, Awareness, Treatment, and Control of Hypertension in Rural and Urban Communities in High-Middle-And Low-Income Countries. *JAMA* (2013) 310(9):959–68. doi:10.1001/jama.2013.184182
 31. Smith KR. *Biofuels, Air Pollution, and Health : A Global Review*. New York: Plenum Press (1987).
 32. Lee M-S, Hang J, Zhang F, Dai H, Su L, Christiani DC. In-home Solid Fuel Use and Cardiovascular Disease: a Cross-Sectional Analysis of the Shanghai Putuo Study. *Environ Health* (2012) 11(1):18. doi:10.1186/1476-069X-11-18
 33. Yan Z, Liu Y, Yin Q, Qiu M. Impact of Household Solid Fuel Use on Blood Pressure and Hypertension Among Adults in China. *Air Qual Atmos Health* (2016) 9(8):931–40. doi:10.1007/s11869-016-0395-2
 34. 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 (Greenwich)* (2022) 24. doi:10.1111/jch.14533
 35. Yu K, Qiu G, Chan KH, Lam KBH, Kurmi OP, Bennett DA, et al. Association of Solid Fuel Use with Risk of Cardiovascular and All-Cause Mortality in Rural China. *Jama* (2018) 319(13):1351–61. doi:10.1001/jama.2018.2151
 36. Song L, Smith GS, Adar SD, Post WS, Guallar E, Navas-Acien A, et al. Ambient Air Pollution as a Mediator in the Pathway Linking Race/ethnicity to Blood Pressure Elevation: The Multi-Ethnic Study of Atherosclerosis (MESA). *Environ Res* (2020) 180:108776. doi:10.1016/j.envres.2019.108776
 37. Liu Z, Hystad P, Zhang Y, Rangarajan S, Yin L, Wang Y, et al. Associations of Household Solid Fuel for Heating and Cooking with Hypertension in Chinese Adults. *J Hypertens* (2020) 39:667–76. doi:10.1097/HJH.0000000000002689
 38. Donaldson K, Stone V, Seaton A, MacNee W. Ambient Particle Inhalation and the Cardiovascular System: Potential Mechanisms. *Environ Health Perspect* (2001) 109(4):523–7. doi:10.1289/ehp.011109s4523

Copyright © 2022 Liu, Li, Zhu, Hystad, Ma, Rangarajan, Zhao, Hu, Yusuf, Li and Tse. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.