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Indoor solid fuel use for cooking and the risk of incidental non-fatal cardiovascular disease among middle-aged and elderly Chinese adults: a prospective cohort study

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ABSTRACT

Objectives The harm of indoor air pollution to health has gradually attracted attention, but the effect of indoor air pollution from burning solid fuels on incidental non-fatal cardiovascular disease (CVD) is not well understood. Under these circumstances, this study examined the association between solid fuel use and incidental non-fatal CVD.

Design The prospective cohort study was conducted in 2011, 2013, 2015 and 2018.

Setting The nationally representative survey was conducted in 28 provinces of China.

Participants This study included 13 544 middle-aged and elderly adults without CVD in the baseline survey, and they were followed for 7 years.

Outcome measures First incidence of non-fatal CVD (heart disease or stroke).

Methods Based on longitudinal data, Cox proportional hazards models were used to assess the effects of solid fuel use and persistent use on incidental CVD events.

Results During the 7-year follow-up period, there were 1533 non-fatal CVD cases. A total of 7310 (54%) participants used solid fuel for cooking at the baseline survey, and 2998 (41%) users continued to use solid fuel. Solid fuel use was associated with incidental non-fatal CVD (HR: 1.18; 95% CI: 1.05 to 1.32) compared with clean fuel, and persistent solid fuel use might lead to a higher risk of incidental non-fatal CVD (HR: 1.38; 95% CI: 1.18 to 1.61) and heart disease (HR: 1.49; 95% CI: 1.24 to 1.81). In the subgroup analysis, the relationship remained significant in the female, elderly, rural and hypertensive groups. However, we found no significant interaction between these risk factors and fuel use (all p<0.05).

Conclusions This cohort study provides evidence for the effects of solid fuel use on incidental non-fatal CVD in middle-aged and elderly Chinese adults. Advocating for the use of clean energy and ventilation stoves is important to cardiovascular health.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ This study first evaluated the impact of persistent solid fuel use on non-fatal cardiovascular disease in China.
- ⇒ Nationwide prospective design and three sensitivity analyses increased the reliability of the results.
- ⇒ There was no way to measure the specific exposure dose and time of each interviewee.
- ⇒ There was recall bias in collecting important information (such as disease status) by questionnaire.

INTRODUCTION

Worldwide, indoor air pollution (IAP) is an important public health problem, and is 1 of the top 10 risk factors for global disease burden and mortality.[1] A total of 1.8 million deaths and 60.9 million disability-adjusted life years can be attributed to IAP for cooking in developing countries.[2] In addition, the damage may be underestimated because indoor cooking with solid fuel also contributes a part of ambient air pollution.[3 4] Even so, as the International Energy Agency reports, nearly 3 billion people lack access to clean or modern energy in low-income and middle-income countries, so they use readily available solid fuels (firewood, straw, coal, animal dung) to meet their daily demands.[5] These fuels are often burned in inefficient and highly polluting stoves, which can exhaust many air pollutants, such as carbon monoxide (CO), nitrogen dioxide, particulate matter (PM) and organic compounds.[6–8] When users inhale these pollutants, they can pass through the alveolar capillaries,[9] eventually reaching the circulatory system or brain,[10 11] which may cause cardiovascular inflammation or other severe problems.[12 13]

Cardiovascular disease (CVD) was the underlying cause of 18.5 million deaths (approximately one-third of all deaths globally) and the leading cause of disability in 2019.[14] In previous studies, exposure to solid fuel use was found to be associated with an increased risk of respiratory infections,[15] tuberculosis,[16] chronic obstructive pulmonary disease,[17] lung cancer,[18] increased carotid intima media thickness[8] and low birth weight.[19] However, few studies have examined the association between solid fuel use and CVD, and most of these studies were cross-sectional studies, small sample studies or studies in other countries.[20–22] Only a few cohort studies have examined the relationship between solid fuel use and cardiopulmonary mortality globally,[23–25] and almost no nationwide cohort studies have investigated incidental non-fatal CVD among the Chinese population.[26] This may be because most studies have focused only on the effects of outdoor air pollution or smoking on CVD[27 28] but have ignored the impacts of IAP from burning solid fuels on CVD.[9 29] Therefore, it is necessary to provide relevant evidence, especially in China.[30]

China is a large developing country with a sizeable population, and many of these people who use solid fuels are threatened by IAP. In addition, due to the long-term use of solid fuels, IAP has a more lasting impact on health and increases the disease burden because of relying on solid fuel.[31] Although people with CVD have higher rates of disability and death than others, there is insufficient evidence to support government intervention on IAP as a risk factor. Therefore, we conducted a nationwide cohort study to examine the association between solid fuel use for cooking and incidental non-fatal CVD (heart disease and stroke) among middle-aged and elderly Chinese adults, and further nationwide cohort studies are needed on this important issue.

METHODS

Study sample

This prospective study was from the China Health and Retirement Longitudinal Study (CHARLS), which is a nationally representative longitudinal study. It is intended to provide a high-quality public microdatabase serving the needs of scientific and policy research on ageing-related issues.[32] The data for CHARLS are available at: http://charls.pku.edu.cn/.[33] In this study, 17708 participants were recruited from 28 Chinese provinces using multistage stratified sampling in 2011 and three follow-up surveys in 2013, 2015 and 2018. Details of the study design have been described elsewhere.[32] In this study, 13544 participants met the study criteria (age >45 years old, no history of CVD at baseline survey, no missing values for primary variables), including 1533 incidental non-fatal CVD, 2884 lost to follow-up or death, and 9127 with no incidental non-fatal CVD. Figure 1 shows more details about the process of sample exclusion.

Assessment of incidental non-fatal CVD events

The outcome of this study was incidental non-fatal CVD (heart disease or stroke). First, according to other studies,[34] non-fatal CVD events were assessed by two standardised questions: ‘Have you been diagnosed with a

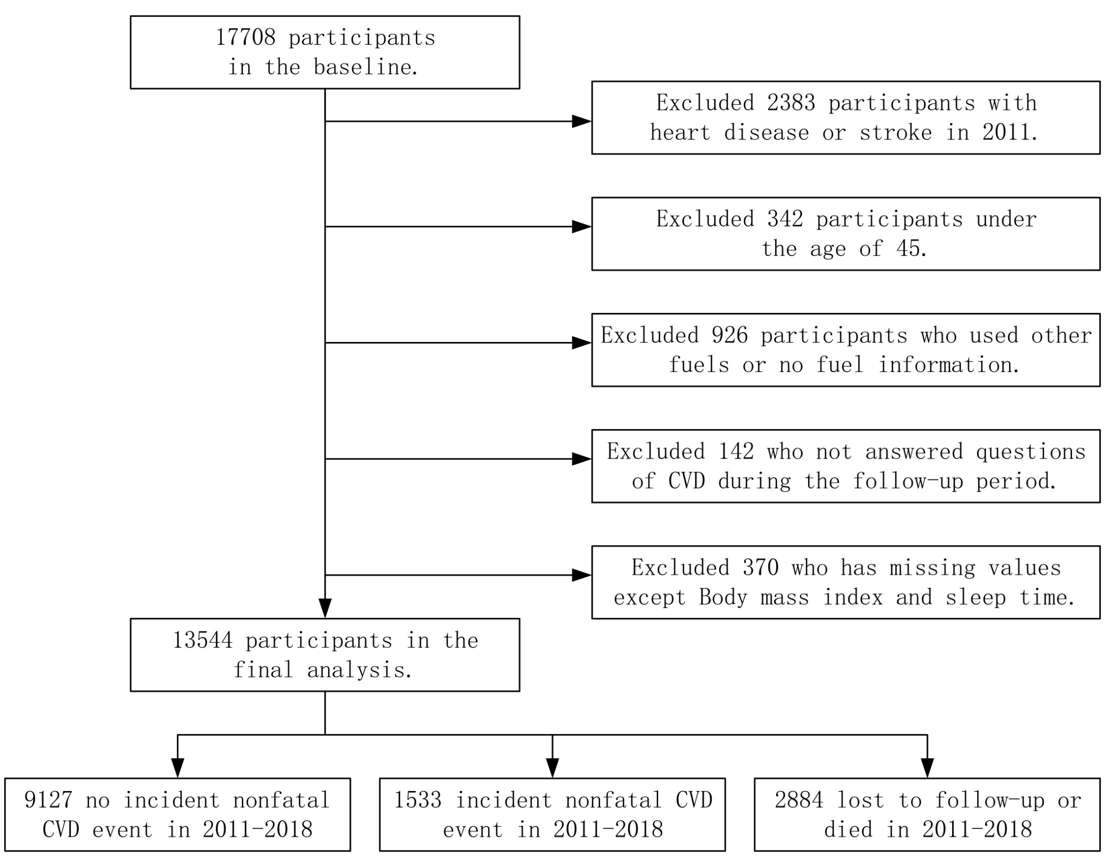

Figure 1 Flow chart of sample exclusion. CVD, cardiovascular disease.

coronary heart disease, heart attack, angina, congestive heart failure or other heart problems by a doctor?' and 'Have you been diagnosed with a stroke by a doctor?' Second, with reference to other similar study,[35] patients who did not die before the next follow-up survey were defined as having non-fatal CVD. Finally, the date of CVD diagnosis was defined as the date of first reporting any CVD event.

Exposure of solid fuel use

Participants' exposure to solid fuel use was assessed by the following standardised question: 'What is the main source of cooking fuel?' Question options included coal, crop residue, wood, natural gas, marsh gas, liquefied petroleum gas, electric, never cook and other fuels.[36] We excluded participants who never cooked and used other fuels. According to the health effects of fuel burning,[37] we defined cooking fuel as clean fuel (natural gas, marsh gas, liquefied petroleum gas, electric) and solid fuel (coal, crop residue and wood). In addition, we defined persistent solid (or clean) fuel users as someone who had been using solid (or clean) fuel through the end of the event, and defined alternate use as any other style of fuel use.

Covariates

At baseline, we incorporated three parts of potential covariates, including sociodemographic status, health behaviour and health status. First, sociodemographic status included residential area (rural village/urban community), gender (male/female), age (45–64/≥65) and highest level of education (did not finish primary school/primary school/middle school/high school above). Second, health behaviours included smoking status (never/former/current), drinking status (never/occasionally/frequently) and sleep time (<6 hours/6–8 hours/>8 hours). Third, health status included hypertension (yes/no, self-reported doctor-diagnosis hypertension), diabetes (yes/no, self-reported doctor-diagnosis diabetes), dyslipidaemia (yes/no, self-reported doctor-diagnosis dyslipidaemia), self-rated health (good/fair/poor) and body mass index (continuous). Body mass index was calculated as weight in kilograms divided by height in metres squared.

Statistical analysis

We conducted multiple imputation to estimate these remaining missing values of sleep time and body mass index using Stata V.14.0. We created 10 replications and pooled the imputed results to account for the missing data using linear regression models.[36]

Baseline data are described as frequencies (percentages) for categorical variables and means (SDs) for continuous variables. Baseline characteristics are summarised according to cooking fuel use, and the X^2 test (for categorical variables) or t-test (for continuous variables) was used to compare the differences in baseline characteristics among different fuel users.

We computed the person-time of follow-up for every respondent from baseline to the dates of incidental non-fatal CVD, death, loss to follow-up or the end of follow-up (2018), whichever came first. Incidence rates of non-fatal CVD events per 1000 person-years were calculated according to cooking fuel use. To examine if there is a relationship between solid fuel use and incident non-fatal CVD events. Cox proportional hazards models were used to calculate HRs with 95% CIs. In addition, we used the Schoenfeld residuals test to verify the proportional hazards assumption and found that the Cox proportional hazards models met the condition ($p>0.05$ for all models). To examine the health impact of persistent solid fuel use, we assessed the effect of persistent solid fuel use on incidental non-fatal CVD events. Subgroup analysis was used to verify the relationship between solid fuel use and incidental CVD. Two-sided $p<0.05$ was defined as statistically significant. All data processing and analyses were performed in Stata software V.14.0 (StataCorp).

Sensitivity analysis

Three sensitivity analyses were conducted. First, we used the data without multiple imputation (10 866 samples) for further analysis. Second, we used the Fine and Gray competing risk model to account for competing risks due to mortality.[38] Third, after considering the clustering effect of the family, we examined the association between (persistent) solid fuel use and incidental CVD events.

Patient and public involvement

Patients were not involved in developing the research questions, measuring the outcomes or designing the overall of the study. Because we could not access specific patient information, we could not communicate the results to them.

RESULTS

Baseline characteristics

A total of 13 544 participants were included in the study. Table 1 shows more details about the characteristics of the baseline participants. A total of 7310 (54%) participants used solid fuel for cooking, 2998 (41%) users continued to use solid fuel during the seven follow-up periods and 3810 (28.13%) participants continued to use clean fuel. In addition, solid fuel users were more likely to be rural residents (94.3%), older adults (29.6%), individuals who had not finished primary school (55.7%), never smokers (59.9%), never drinkers (67%), individuals who had a sleep time of 6–8 hours (59.2%), individuals who had no history of diabetes disease (96%), individuals who had dyslipidaemia disease (94.4%), individuals who had a fair self-rated health status (67.1%) and individuals who had a lower body mass index (mean, SD: 23.93, 3.59) ($p<0.01$ for all).

Table 1 Characteristics of baseline participants according to cooking fuel use

Characteristics	Total sample (N=13544)	Clean fuel users (n=6234)	Solid fuel users (n=7310)	P value
Residential area, N (%)				<0.001
Rural village	10546	3653 (58.6)	6893 (94.3)	
Urban community	2998	2581 (41.4)	417 (5.7)	
Gender, N (%)				0.561
Male	6524	2986 (47.9)	3538 (48.4)	
Female	7020	3248 (52.1)	3772 (51.6)	
Age, N (%)				<0.001
45–64	10032	4887 (78.4)	5145 (70.4)	
>65	3512	1347 (21.6)	2165 (29.6)	
Highest level of education, N (%)				<0.001
Did not finish primary school	6155	2085 (33.4)	4070 (55.7)	
Primary school	2885	1292 (20.7)	1593 (21.8)	
Middle school	2810	1577 (25.3)	1233 (16.9)	
High school or above	1694	1280 (20.5)	414 (5.7)	
Smoke status, N (%)				<0.001
Never	8337	3956 (63.5)	4381 (59.9)	
Former	1079	501(8)	578 (7.9)	
Current	4128	1777 (28.5)	2351 (32.2)	
Drinking status, N (%)				0.007
Never	8982	4083 (65.5)	4899 (67)	
Occasionally	1079	545 (8.7)	534 (7.3)	
Frequently	3483	1606 (25.8)	1877 (25.7)	
Sleep time, N (%)				<0.001
6 hours	3813	1507 (24.2)	2306 (31.5)	
6–8 hours	8605	4281 (68.7)	4324 (59.2)	
8 hours	1126	446 (7.2)	680 (9.3)	
Hypertension, N (%)				0.101
No	10779	4923 (79)	5856 (80.1)	
Yes	2765	1311 (21)	1454 (19.9)	
Diabetes, N (%)				<0.001
No	12915	5898 (94.6)	7017 (96)	
Yes	629	336 (5.4)	293 (4)	
Dyslipidaemia, N (%)				<0.001
No	12562	5665 (90.9)	6897 (94.4)	
Yes	982	569 (9.1)	413 (5.6)	
Self-comment of health, N (%)				<0.001
Good	3583	2028 (32.5)	1555 (21.3)	
Fair	6535	3078 (49.4)	3457 (47.3)	
Poor	3426	1128 (18.1)	2298 (31.4)	
Styles of using fuel, N (%)				<0.001
Persistent clean fuel use	3810	3810 (61.1)	0 (0)	
Alternate use	6736	2424 (38.9)	4312 (59)	
Persistent solid fuel use	2998	0 (0)	2998 (41)	
Body mass index, mean (SD)	23.41 (3.59)	23.93 (3.59)	22.97 (3.53)	<0.001

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Table 2 Association between solid fuel use and incident non-fatal cardiovascular disease events

Outcomes	Cases, no	Incidence rate, per 1000 person-years	HR (95% CI) Model 1	Model 2	Model 3
Non-fatal cardiovascular disease					
Cooking fuel use					
Clean fuel use	639	19.36	Reference	Reference	Reference
Solid fuel use	894	21.48	1.22 (1.09 to 1.37)	1.21 (1.08 to 1.36)	1.18 (1.05 to 1.32)
Styles of using fuel					
Persistent clean fuel use	404	19.41	Reference	Reference	Reference
Alternate use	730	19.49	1.07 (0.94 to 1.22)	1.06 (0.93 to 1.21)	1.04 (0.92 to 1.19)
Persistent solid fuel use	399	24.42	1.41 (1.21 to 1.64)	1.40 (1.20 to 1.63)	1.38 (1.18 to 1.61)
Non-fatal heart disease					
Cooking fuel use					
Clean fuel use	435	13.2	Reference	Reference	Reference
Solid fuel use	571	13.74	1.18 (1.03 to 1.37)	1.18 (1.02 to 1.36)	1.15 (0.99 to 1.32)
Styles of using fuel					
Persistent clean fuel use	271	13.04	Reference	Reference	Reference
Alternate use	465	12.43	1.06 (0.90 to 1.24)	1.05 (0.90 to 1.24)	1.04 (0.89 to 1.22)
Persistent solid fuel use	270	16.54	1.53 (1.27 to 1.84)	1.52 (1.26 to 1.84)	1.49 (1.24 to 1.81)
Non-fatal stroke					
Cooking fuel use					
Clean fuel use	262	7.97	Reference	Reference	Reference
Solid fuel use	374	9.02	1.19 (1.00 to 1.43)	1.18 (0.99 to 1.41)	1.15 (0.96 to 1.37)
Styles of using fuel					
Persistent clean fuel use	165	7.97	Reference	Reference	Reference
Alternate use	320	8.55	1.11 (0.91 to 1.36)	1.10 (0.90 to 1.35)	1.09 (0.90 to 1.34)
Persistent solid fuel use	151	9.32	1.20 (0.94 to 1.53)	1.19 (0.93 to 1.52)	1.18 (0.92 to 1.50)

In model 1, we adjusted for gender, age, residential area and education. In model 2, we adjusted for gender, age, residential area, education, smoking status, drinking status and sleeping time. In model 3, we adjusted for gender, age, residential area, education, smoking status, drinking status, sleeping time, hypertension, dyslipidaemia, self-rated health and body mass index.

Incidence of CVDs

During the 7-year follow-up period, 1533 participants experienced non-fatal CVD cases (heart disease, 1006 cases; stroke, 636 cases). The incidence rate of non-fatal CVD of solid fuel users (21.48 per 1000 person-years) was higher than that of clean fuel users (19.36 per 1000 person-years), and persistent solid fuel users had the highest incidence rate of non-fatal CVD (24.42 per 1000 person-years).

The association between solid fuel use and non-fatal CVD

Table 2 shows more details about the association between solid fuel use and non-fatal CVD. After adjusting all the covariates (in model 3), baseline solid fuel users had a higher risk of incident non-fatal CVD (HR: 1.18; 95% CI: 1.05 to 1.32), and persistent use of solid fuel amplified the negative impact. In model 3, compared with references, persistent solid fuel use was independently associated with a 38% increased risk of incidental non-fatal CVD and a 49% risk of incidental heart disease (CVD: HR 1.38; 95% CI 1.18 to 1.61; heart disease: HR 1.49; 95% CI 1.24 to 1.81).

Urban community (HR: 1.35; 95% CI: 1.17 to 1.55), ≥65 years old (HR: 1.41; 95% CI: 1.26 to 1.58), current smoker (HR: 1.32; 95% CI: 1.08 to 1.61), sleep time <6 hours (HR: 1.14; 95% CI: 1.02 to 1.28), hypertension (HR: 1.76; 95% CI: 1.57 to 1.98), dyslipidaemia (HR: 1.32; 95% CI: 1.12 to 1.55), poor health status (HR: 1.78; 95% CI: 1.53 to 2.07) and higher body mass index (HR: 1.03; 95% CI: 1.01 to 1.04) were risk factors for incidental non-fatal CVD. More details about the risk factors for incidental CVD events are provided in online supplemental table A.1.

In the Fine and Gray competing risk models, we considered the competing risk of mortality for the outcome. After adjusting for confounding factors, we found results that were basically consistent with model 3, except that solid fuel use increased the risk of incidental non-fatal heart disease (Sub-distribution Hazard Ratio (SHR):

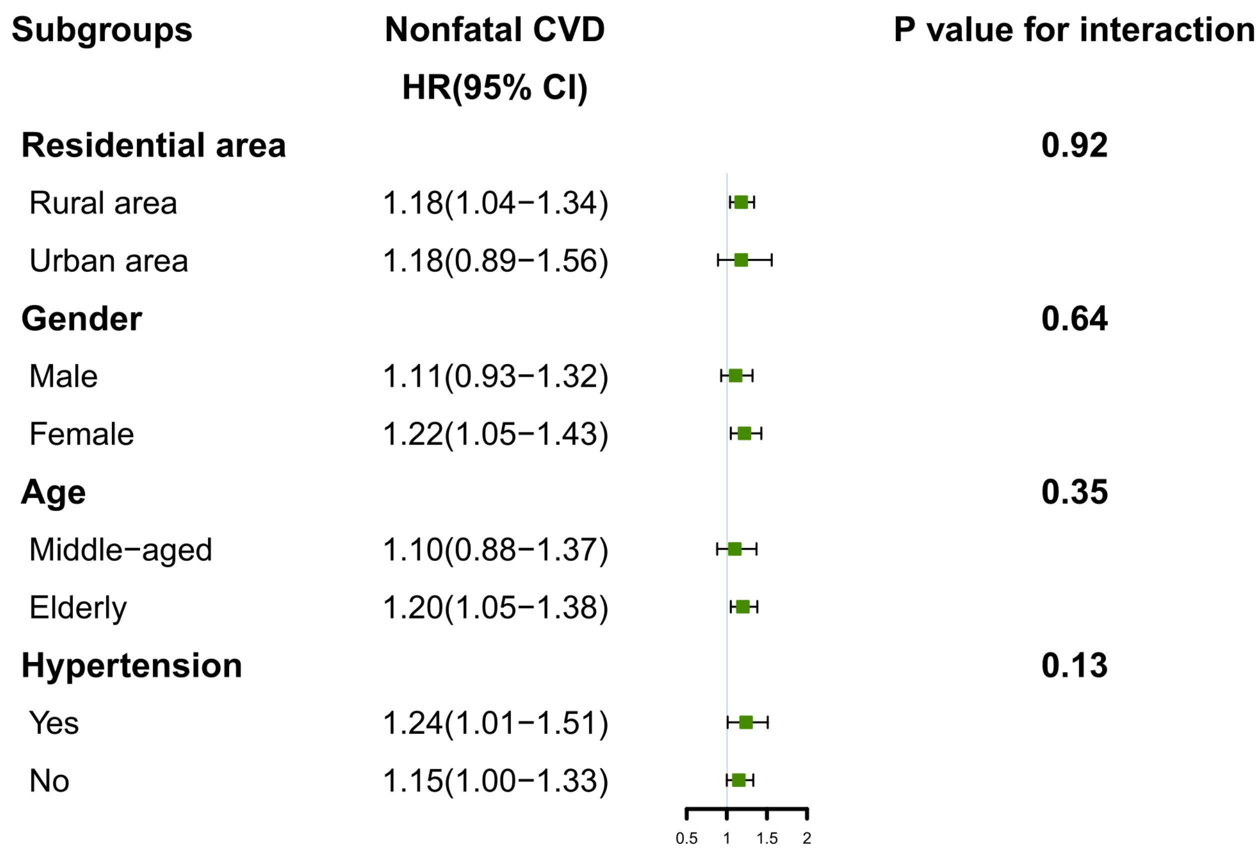

Figure 2 Association between solid fuel use and non-fatal CVD event risk stratified by different factors. CVD, cardiovascular disease.

1.17; 95% CI: 1.02 to 1.34) in the competing risk model (online supplemental table A.2). In another sensitivity analysis, similar results were found when 10 866 records were obtained without multiple imputation (online supplemental table A.3). In addition, after considering the clustering effect of every family, the associations between solid fuel use, persistent solid fuel and incidental non-fatal CVD were still significant (online supplemental table A.4).

Association between solid fuel use and non-fatal CVD event risk stratified by different factors

In the subgroup analysis, the relationship remained significant in the female (HR: 1.22; 95% CI: 1.05 to 1.43), elderly (HR: 1.20; 95% CI: 1.05 to 1.38), rural (HR: 1.18; 95% CI: 1.04 to 1.34), hypertensive groups (HR: 1.24; 95% CI: 1.01 to 1.51). However, no significant interaction effects between solid fuel use and these factors were found (all $p<0.05$), and these results are presented by the forest plots in figure 2.

DISCUSSION

This study found 7310 (54%) participants used solid fuel for cooking at baseline, and 2998 (41%) users continued to use solid fuel during the follow-up period. Solid fuel use was associated with incidental non-fatal CVD compared with clean fuel, and persistent solid fuel use can lead to a higher risk of incidental non-fatal CVD compared with the reference. In addition, we found that the association between solid fuel use and incidental non-fatal CVD was significant among rural residents, females, the elderly and people with hypertension compared with clean fuel users.

In Chinese villages, even though electricity has been popularised, solid fuel is still widely used. Some solid fuels (such as firewood, straw and animal dung) are available everywhere in some poorer areas, which influences villagers to save money by using these fuels for a long time. In addition, some poor families do not have a stove or good ventilation, which increases the health risk of attaching to IAP from using solid fuel.[39] Therefore, pollutants from burning solid fuels produce long-term and lasting harm to people under the circumstances.

The studies found that female users of solid fuel had an increased risk of incidental CVD, which is consistent with other studies.[40] As a Chinese tradition, men usually work away from home, and women must spend more time taking care of their family and cooking. Therefore, women are more exposed to IAPs from burning solid fuel and experience IAP-related health problems. In addition, elderly users of solid fuels are more at risk from solid fuels, and other previous studies also found the same problems.[24] In the elderly population, the function of cardiovascular declines and exposure time increases persistently with age, which makes these people more vulnerable to coping with adverse risk factors. Therefore, their daily use of solid fuel increases their cardiovascular burden. Moreover, hypertension is a major risk factor for incidental CVD and a major health problem in middle-aged and elderly populations, and this disease can lead to arteriosclerosis and abnormal constriction of the arteries over time. Studies have reported that some IAPs (CO and PM) from burning solid fuels can exacerbate vascular inflammation and increase vascular burden.[41] If patients with hypertension do not stop using solid fuels, there may be a combined negative effect on cardiovascular function and eventually lead to CVD.

These results support the opinion that solid fuel use for cooking increases the risk of incidental non-fatal CVD and health harm among Chinese people. More cohort studies should be conducted to verify these results. Meanwhile, necessary measures must be taken to reduce the health threat from IAP. Using clean energy is the most efficient way,[42] but some people may struggle to pay for their daily clean energy consumption. This may be because some solid fuels are available everywhere throughout their life. Therefore, governments must consider the actual situation to gradually implement clean energy popularisation and promote the use of stoves with high-ventilation efficiency in poor areas. In addition, governments should vigorously develop local industries by using the local labour force and environment. After all, human health benefits more from the fruit of economic development.

The study has some advantages. Most previous studies were cross-sectional studies, but we used 7 years of follow-up data to enhance statistical power. In addition, this is the first nationwide cohort study that examined the association between persistent solid fuel use and incidental non-fatal CVD in a Chinese population. However, this study still has some unsolvable limitations. First, it only included Chinese participants, so the results may not generalise to other countries. Second, some risk factors for the association between solid fuel use and CVD events, such as indoor ventilation condition, income, dietary habit and physical exercise, were not adjusted for. Third, there may have been recall bias in collecting important information (such as disease status) by questionnaire. Finally, we could not acquire accurate information exposure time and doses; therefore, we used the type of cooking fuel use as study variables.

CONCLUSIONS

As a cohort study that followed individuals in China for 7 years, the study suggests that solid fuel use for cooking was associated with incidental non-fatal CVD events compared with clean fuel use and that persistent solid fuel use can lead to a higher risk of incidental non-fatal CVD in middle-aged and elderly Chinese populations. In addition, we found that the association between solid fuel use and incidental non-fatal CVD was significant among rural residents, females, the elderly and people with hypertension compared with clean fuel users. To our knowledge, our study is the first to find evidence from a nationwide cohort study about the effects of persistent solid fuel use on incidental non-fatal CVD in a middle-aged and elderly Chinese population. Advocating for the use of clean energy and ventilation stoves is important to the protection of cardiovascular health.

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Contributors All authors contributed fully to the paper. HJ and LZ designed the study. HJ conducted the analysis, drafted the manuscript and revised the manuscript. QC checked the data analysis results. QC, RW, JX, XC, LD, YC, YP, YD and MS made substantial contributions to revising the manuscript for important intellectual content. All authors agreed on the final version to be submitted. LZ is the guarantor of this paper. The guarantor accepts full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This study involves human participants and the ethics application for collecting data on human subjects in CHARLS was approved by the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. Data of China Health and Retirement Longitudinal Study can be accessed through its website (http://charls.pku.edu.cn/).

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