nature human behaviour

Article

https://doi.org/10.1038/s41562-022-01486-5

Cooking and future risk of all-cause and cardiopulmonary mortality

Received: 5 January 2022

Accepted: 24 October 2022

Published online: 8 December 2022

Check for updates

Kuai Yu[1,7], Jun Lv[2,7], Gang Liu[3,7], Canqing Yu[2], Yu Guo[4], Ling Yang[5], Yiping Chen[5], Chaolong Wang[6], Zhengming Chen[5], Liming Li[2,8] & Tangchun Wu[1,8]

Cooking is practiced worldwide and is associated with multiple social, economic and environmental factors; thus, understanding cooking-related health effects would have broad public health implications. Here, we show that after an average 9.9 years of follow-up for 510,106 Chinese adults, always cooking with clean fuels was associated with lower risks of all-cause (0.90 [95% confidence interval 0.87–0.93]; $P = 1.39 \times 10^{-9}$), cardiovascular (0.83 [0.78–0.87]; $P = 6.83 \times 10^{-11}$) and respiratory (0.88 [0.79–0.99]; $P = 0.026$) mortality compared with non-cooking, of which 50.1% (14.5–85.6%) to 66.0% (38.5–85.8%) could be attributed to increased household physical activity. The mortality risks decreased with extended duration of cooking with clean fuels in dose–response manners, with the lowest hazard ratios of 0.74 (0.68–0.80; $P = 1.20 \times 10^{-13}$) for all-cause and 0.62 (0.55–0.71; $P = 3.15 \times 10^{-12}$) for cardiovascular mortality among never-smokers reported over 25 years of cooking. Our findings suggest lower future mortality risks may be gained only when cooking with clean fuels.

Cooking is a fundamental activity of human beings, the practice of which closely relates to multiple social, economic and environmental factors[1–3]. Understanding the health effects associated with cooking has broad public health implications[4]. Concerns have long been expressed by previous researchers in the field of cooking regarding the pollution generated during cooking, either from fuel combustion or from oil fumes[5–7], which has been reported to be a leading contributor to the global mortality and morbidity burden[8–11]. Although the cooking environment has been markedly improved after decades of efforts on promoting the use of cleaner fuels and ventilation facilities[12–14], the current role of cooking in affecting health and even survival remains largely unclear. Further research is therefore crucial to investigate, on a large scale, the associations between cooking and health outcomes.

Several studies have linked cooking with health outcomes[3], for example, lower risks of diabetes[15,16] and hypertension[17,18] were reported among individuals who cooked more frequently; however, to our best knowledge, only one prospective cohort study has investigated the association of cooking with mortality[19]. This 10-year prospective cohort study of 1,888 participants aged over 65 years in Taiwan, China observed a 41% lower mortality risk among adults who cooked their meals over five times per week compared with those never-cooking, indicating that cooking might be favourable for longevity. However, this study was confined to elder adults from a single area, thus affecting the generalizability of the findings to other populations. The small sample size in this study also limited its ability to examine the impact of cooking on mortality from specific causes, particularly from cardiopulmonary

[1]Department of Occupational and Environmental Health and Department of Epidemiology and Biostatistics, Key Laboratory of Environment and Health, Ministry of Education and State Key Laboratory of Environmental Health (Incubating), School of Public Health, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China. [2]Department of Epidemiology and Biostatistics, School of Public Health, Peking University Health Science Center, Beijing, China. [3]Department of Nutrition and Food Hygiene, Hubei Key Laboratory of Food Nutrition and Safety, School of Public Health, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China. [4]Chinese Academy of Medical Sciences, Beijing, China. [5]Clinical Trial Service Unit & Epidemiological Studies Unit (CTSU), Nuffield Department of Population Health, University of Oxford, Oxford, UK. [6]Department of Epidemiology and Biostatistics, School of Public Health, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China. [7]These authors contributed equally: Kuai Yu, Jun Lv, Gang Liu. [8]These authors jointly supervised this work: Liming Li, Tangchun Wu. e-mail: lmlee@vip.163.com; wut@mails.tjmu.edu.cn

https://doi.org/10.1038/s41562-022-01486-5

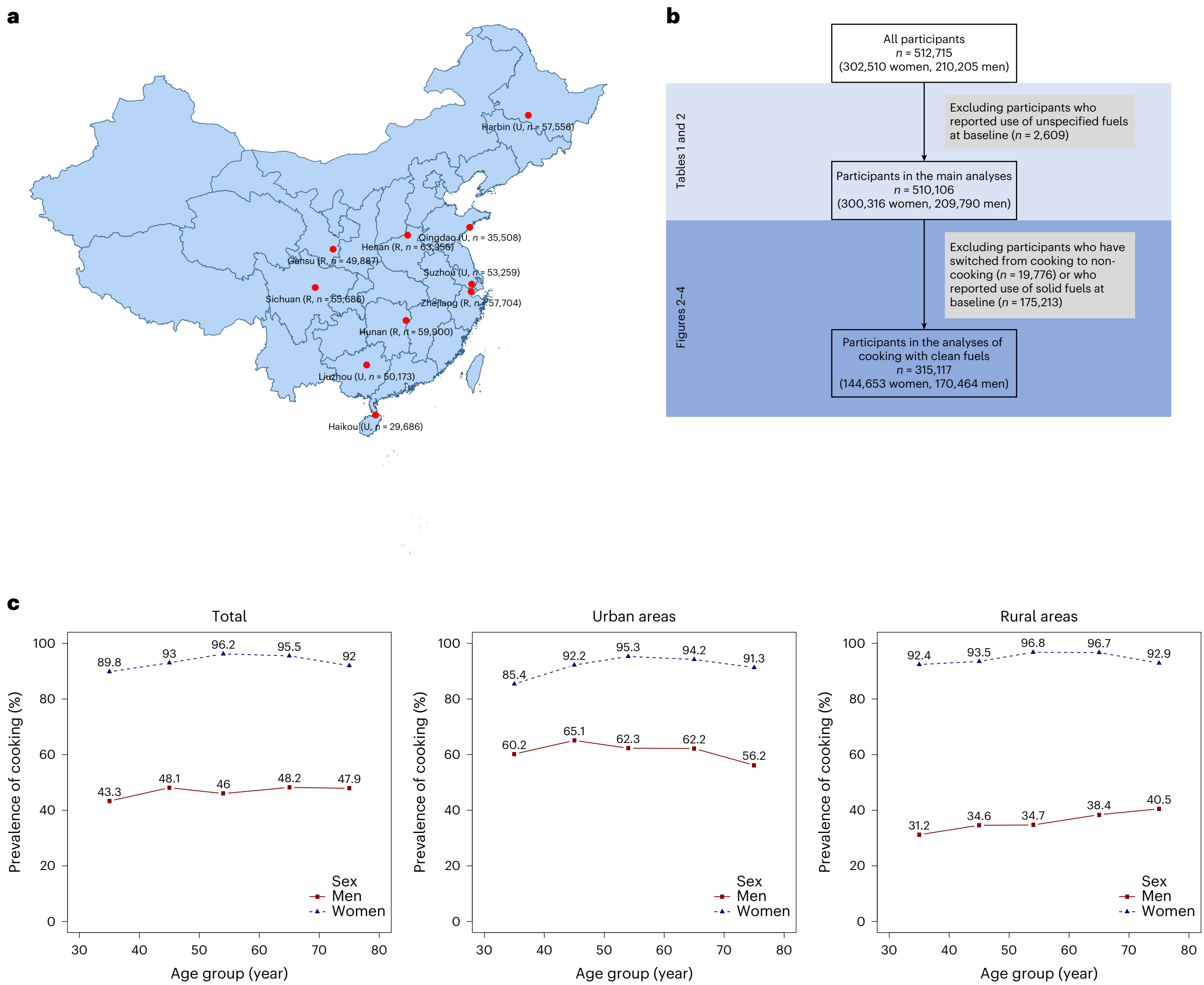

Fig. 1 | Overview and cooking prevalence of the study ($n = 512{,}715$). a, Locations of ten study areas of the CKB study. Red circles are the ten study areas of the CKB study and number recruited at baseline in each area is shown in brackets (adapted from ref. [34]). **b**, Flowchart of the study. **c**, Baseline prevalence of cooking in Chinese men and women, by age and residence. The box indicates the cooking prevalence, which was calculated by dividing the participants reported cooking currently by the total participants.

diseases, which accounted for almost 40% of worldwide premature deaths as estimated in the 2019 Global Disease Burden study[20]. Furthermore, although it has been years since worldwide effort on transitioning towards cleaner cooking[12], the long-term effect of cooking with clean fuels on mortality risk remains largely unclear, which is important to inform further initiatives on energy and public health policies.

Here, we used a 10-year prospective data of 510,106 adults from the China Kadoorie Biobank study (CKB) to examine the association of cooking (including non-cooking to cooking, always cooking with clean fuels and always cooking with solid fuels) with all-cause and cardiopulmonary mortality in comparison with always non-cooking, with never-smoker and ever-smoker examined together or separately. We also examined the association of long-term cooking clean fuel use with mortality risk.

Results

Baseline characteristics of the study participants

Of the 510,106 participants, the median (interquartile range, IQR) age and body mass index (BMI) was 51.5 (IQR, 16.8) years and 23.4 (IQR, 4.6), 59.0% were women and 44.3% of the participants were from urban areas. At baseline, the prevalence of cooking is between 43.3% and 48.2% of men and 89.8% and 96.2% of women, depending on age (Fig. 1). In general, participants reported cooking currently were more likely to be women, live in urban areas, educated less, earned less household income, smoked less, drank less alcohol, used vegetable cooking oil, consumed more fresh fruits and preserved vegetables, compared with those not cooking (Table 1). In the resurvey, 86% of the participants reported the same category of cooking as at baseline and the kappa value was 0.66 (95% confidence interval (CI) 0.64–0.67; Supplementary Table 1).

Association of cooking with all-cause and cardiopulmonary mortality

During an average of 9.9 ± 1.8 years of follow-up, we documented 42,788 total deaths, including 16,817 deaths from cardiovascular causes and 4,027 from respiratory causes. Compared with always non-cooking, the multivariable-adjusted hazard ratios (HRs) of

https://doi.org/10.1038/s41562-022-01486-5

Table 1 | Baseline characteristics of the study participants according to cooking categories

Characteristic	Total				Never-smoker				Ever-smoker			
	Always non-cooking[a]	Cooking to non-cooking	Always cooking with clean fuels	Always cooking with solid fuels	Always non-cooking	Cooking to non-cooking	Always cooking with clean fuels	Always cooking with solid fuels	Always non-cooking	Cooking to non-cooking	Always cooking with clean fuels	Always cooking with solid fuels
n	131,383	19,776	183,734	175,213	30,042	10,675	133,309	141,273	101,341	9,101	50,425	33,940
Age (year)	51.1 (17.6)	53.3 (19.1)	51.3 (16.1)	51.8 (16.8)	47.6 (18.7)	53.8 (21.0)	51.3 (15.8)	50.8 (16.1)	51.9 (17.1)	52.9 (16.5)	51.3 (17.0)	55.9 (16.2)
Female sex (%)	10.9	51.3	70.9	83.0	46.0	88.0	93.2	97.4	0.6	8.3	12.1	23.2
Urban residence (%)	31.2	32.4	85.1	8.8	46.0	63.5	85.0	8.2	26.8	72.4	85.3	11.1
Education (%)												
Primary school or below	45.4	44.6	35.0	72.2	39.6	49.6	37.4	73.0	47.1	38.7	28.5	68.6
Middle school	31.8	29.0	31.9	21.6	28.6	25.2	30.2	21.3	32.7	33.5	36.2	23.1
High school or above	22.9	26.4	33.2	6.2	31.8	25.2	32.4	5.7	20.2	27.8	35.2	8.3
Occupation (%)												
Agriculture and related	51.5	18.4	8.0	71.7	32.6	16.7	8.2	71.3	57.1	20.3	7.8	73.2
Factory worker	15.7	20.8	21.8	4.3	21.5	16.1	17.2	3.7	14.0	26.4	33.9	6.7
Unemployed	16.3	34.9	48.6	19.6	23.1	43.2	53.5	21.1	14.2	25.2	35.5	13.3
Other	16.5	25.9	21.6	4.5	22.9	24.0	21.1	3.9	14.7	28.1	22.8	6.8
Household income (%)[b]												
<10,000 yuan $year^{-1}$	28.1	17.9	13.1	45.3	19.7	19.8	13.3	44.8	30.5	15.7	12.8	47.4
10,000–19,999 yuan $year^{-1}$	28.5	26.8	28.9	29.6	26.0	27.9	29.1	30.4	29.3	25.4	28.4	26.1
>19,999 yuan $year^{-1}$	43.4	55.3	58.0	25.1	54.4	52.3	57.7	24.8	40.2	58.9	58.8	26.4
Ever-drinker (yes, %)	72.7	58.5	52.5	41.3	49.3	36.3	40.2	33.3	79.6	84.5	84.9	74.2
Passive smoking (yes, %)	55.7	55.0	48.0	57.7	41.7	48.6	44.8	57.2	59.9	62.5	56.5	60.0
Use vegetable cooking oil (yes, %)	7.8	18.2	84.3	65.9	10.6	18.8	83.6	65.2	6.9	17.5	86.4	68.4
At least some cookstove ventilated (yes, %)	73.3	80.9	89.3	63.6	79.3	79.8	89.2	63.5	71.5	82.2	89.6	63.7
Daily fresh fruit intake (yes, %)	12.4	24.3	36.4	4.4	21.6	27.6	40.3	4.4	9.7	20.4	27.7	4.7
Daily preserved vegetable intake (yes, %)	12.4	23.0	23.1	10.1	11.8	19.6	22.2	8.9	12.5	27.1	25.8	15.0

https://doi.org/10.1038/s41562-022-01486-5

Table 1 (continued) | Baseline characteristics of the study participants according to cooking categories

Characteristic	Total				Never-smoker				Ever-smoker			
	Always non-cooking[a]	Cooking to non-cooking	Always cooking with clean fuels	Always cooking with solid fuels	Always non-cooking	Cooking to non-cooking	Always cooking with clean fuels	Always cooking with solid fuels	Always non-cooking	Cooking to non-cooking	Always cooking with clean fuels	Always cooking with solid fuels
Daily meat intake (yes, %)	27.3	42.9	46.9	11.0	32.8	38.5	44.7	10.0	25.7	48.0	52.8	15.5
Physical activity (MET-hr d^{-1}) [c]	17.2 (24.1)	13.1 (24.5)	9.3 (20.6)	10.6 (19.8)	15.6 (22.9)	10.3 (22.8)	6.6 (18.0)	9.9 (19.4)	17.8 (24.3)	15.8 (24.5)	13.7 (24.0)	13.1 (21.0)
Household physical activity (h $week^{-1}$)	4.0 (7.0)	7.0 (12.0)	14.0 (14.0)	21.0 (10.0)	7.0 (8.0)	7.0 (10.0)	15.0 (7.0)	21.0 (14.0)	3.0 (7.0)	3.0 (7.0)	7.0 (9.0)	14.0 (14.0)
BMI (kg m^{-2})	22.9 (4.5)	23.8 (4.6)	24.1 (4.5)	23.0 (4.5)	23.3 (4.3)	23.8 (4.7)	24.0 (4.5)	23.2 (4.5)	22.8 (4.5)	23.8 (4.4)	24.2 (4.5)	22.3 (4.4)
Waist circumference (cm)	80.1 (13.9)	81.3 (14.2)	81.0 (13.8)	77.9 (13.0)	79.2 (13.8)	80.0 (13.9)	79.8 (12.9)	78.0 (13.0)	80.4 (13.8)	83.0 (14.0)	84.5 (13.5)	77.6 (13.2)
Systolic blood pressure (mmHg)	128.5 (24.5)	128.5 (27.5)	126.5 (26.5)	129.0 (27.0)	126.0 (26.0)	128.0 (30.0)	125.0 (27.0)	128.5 (27.5)	129.0 (24.0)	129.0 (25.0)	129.5 (24.5)	131.0 (25.0)
Major chronic diseases at baseline (yes, %)	12.1	17.7	11.5	11.0	9.9	18.5	11.0	9.1	12.8	16.8	13.0	18.6
Hypertension (yes, %)	33.6	38.2	33.8	35.3	31.4	39.2	32.4	34.7	34.3	37.1	37.5	37.9
Diabetes (yes, %)	4.8	8.9	7.8	4.4	5.6	10.0	7.7	4.5	4.6	7.6	8.1	4.3
Unsatisfied with life (yes, %)[d]	3.4	5.3	5.4	3.3	3.4	4.6	5.0	3.1	3.3	6.0	6.7	4.3
Poor self-rated health (yes, %)	8.7	14.8	8.7	12.9	8.0	16.9	8.8	12.4	8.9	12.4	8.4	14.8
Major depression (yes, %)[e]	0.4	0.6	0.6	0.9	0.4	0.7	0.6	0.9	0.4	0.5	0.5	1.0
Sleep disturbance (yes, %)[f]	13.3	18.5	15.5	20.5	13.4	20.1	16.3	20.2	13.3	16.0	13.3	21.7

Data are medians (IQRs; for continuous variables) or percentages (for categorical variables). [a] Non-cooking denotes cooking monthly or less. [b] At the exchange rate as of October 2022, 100 yuan ≈ US$14. [c] MET denotes metabolic equivalent of task. [d] Unsatisfied with life was defined by the report of 'being unsatisfied' or 'very unsatisfied' with life. [e] Major depression was defined by the CIDI-SF diagnostic criteria of major depressive episode. [f] Sleep disturbance was defined by the report of having disorders of 'initiating and maintaining sleep' or 'early morning awakening' or 'daytime dysfunction'.

Table 2 | Adjusted HRs for all-cause and cardiopulmonary mortality by cooking categories

Mortality	All-cause mortality			Cardiovascular mortality			Respiratory mortality		
	No. of deaths (%)	HR (95% CI)	*P* value	No. of deaths (%)	HR (95% CI)	*P* value	No. of deaths (%)	HR (95% CI)	*P* value
Total									
Always non-cooking	14,301 (10.9)	Ref.		5,747 (4.4)	Ref.		1,395 (1.1)	Ref.	
Cooking to non-cooking	2,371 (12.0)	1.30 (1.24–1.36)	1.37×10^{-26}	1,132 (5.7)	1.46 (1.36–1.56)	3.25×10^{-25}	244 (1.2)	1.40 (1.21–1.61)	5.12×10^{-6}
Always cooking with clean fuels	10,831 (5.9)	0.90 (0.87–0.93)	1.39×10^{-9}	3,709 (2.0)	0.83 (0.78–0.87)	6.83×10^{-11}	789 (0.4)	0.88 (0.79–0.99)	0.026
Always cooking with solid fuels	15,285 (8.7)	1.04 (1.01–1.07)	0.008	6,229 (3.6)	1.06 (0.99–1.14)	0.105	1,599 (0.9)	1.15 (1.04–1.26)	0.004
Never-smoker									
Always non-cooking	2,270 (7.6)	Ref.		993 (3.3)	Ref.		180 (0.6)	Ref.	
Cooking to non-cooking	1,296 (12.1)	1.35 (1.25–1.46)	1.88×10^{-13}	686 (6.4)	1.40 (1.25–1.58)	3.32×10^{-8}	119 (1.1)	1.58 (1.21–2.08)	0.001
Always cooking with clean fuels	6,053 (4.5)	0.78 (0.73–0.83)	1.73×10^{-13}	2,078 (1.6)	0.67 (0.61–0.75)	1.60×10^{-13}	377 (0.3)	0.87 (0.69–1.10)	0.242
Always cooking with solid fuels	9,724 (6.9)	1.00 (0.93–1.06)	0.976	4,229 (3.0)	0.91 (0.81–1.03)	0.124	815 (0.6)	1.19 (0.95–1.49)	0.130
Ever-smoker									
Always non-cooking	12,031 (11.9)	Ref.		4,754 (4.7)	Ref.		1,215 (1.2)	Ref.	
Cooking to non-cooking	1,075 (11.8)	1.12 (1.05–1.20)	0.009	446 (4.9)	1.27 (1.15–1.41)	5.64×10^{-6}	125 (1.4)	1.25 (1.03–1.52)	0.025
Always cooking with clean fuels	4,778 (9.5)	0.96 (0.92–0.99)	0.029	1,631 (3.2)	0.91 (0.85–0.98)	0.009	412 (0.8)	0.91 (0.79–1.04)	0.179
Always cooking with solid fuels	5,561 (16.4)	1.09 (1.04–1.14)	2.56×10^{-4}	2,000 (5.9)	1.12 (1.02–1.22)	0.013	784 (2.3)	1.13 (1.02–1.26)	0.023

Cox regression was used to estimate the HRs and 95% CIs with stratification according to age-at-risk, sex and study area and adjustment for education level, occupation, household income, smoking status (when appropriate), alcohol intake, passive smoking, physical activity, BMI, major chronic diseases at baseline and heating with solid fuels. Ref. denotes the reference group who reported always non-cooking. All statistical tests were two-sided. $P<0.05$ was considered significant.

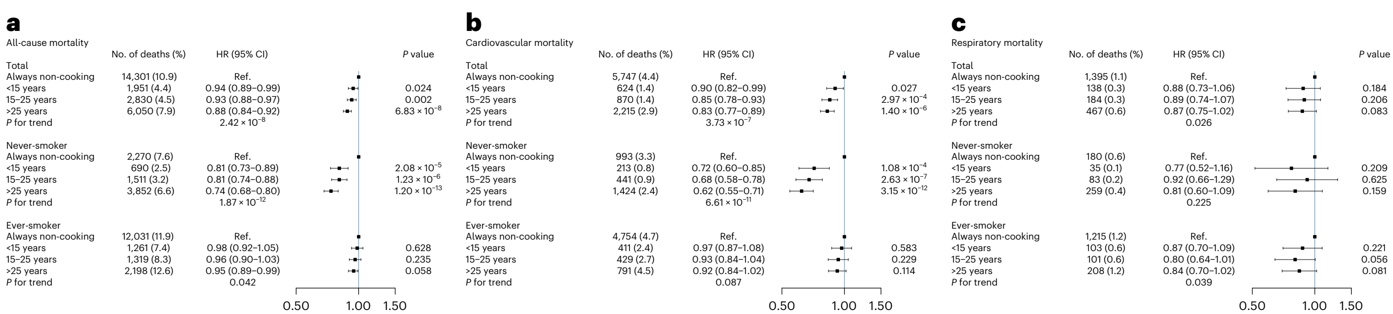

Fig. 2 | Adjusted HRs for all-cause and cardiopulmonary mortality by duration of cooking with clean fuels. a–c, Cox regression was used to estimate the HRs and 95% CIs for all-cause mortality (**a**; $n=315{,}117$), cardiovascular mortality (**b**; $n=315{,}117$) and respiratory mortality (**c**; $n=315{,}117$) with stratification according to age-at-risk, sex and study area and adjustment for education level, occupation, household income, smoking status (when appropriate), alcohol intake, passive smoking, physical activity, BMI, major chronic diseases at baseline and heating with solid fuels. The effect estimates represent the HRs from the Cox regression and the error bars represent 95% CIs. The linear trend was tested through entering each cooking group as a continuous variable in the Cox models. Ref. denotes the reference group who reported always non-cooking. All statistical tests were two-sided. $P<0.05$ was considered significant.

cooking previously but switched to non-cooking currently were 1.30 (1.24–1.36; $P=1.37\times10^{-26}$) for all-cause mortality, 1.46 (1.36–1.56; $P=3.25\times10^{-25}$) for cardiovascular mortality and 1.40 (1.21–1.61; $P=5.12\times10^{-6}$) for respiratory mortality, respectively. Participants reporting cooking with clean fuels had lower risks of all-cause (HR, 0.90 [0.87–0.93]; $P=1.39\times10^{-9}$), cardiovascular (0.83 [0.78–0.87]; $P=6.83\times10^{-11}$) and respiratory mortality (0.88 [0.79–0.99]; $P=0.026$) than those always non-cooking. Participants reporting cooking with solid fuels had higher risks of all-cause (HR, 1.04 [1.01–1.07]; $P=0.008$) and respiratory (HR, 1.15 [1.04–1.26]; $P=0.004$) mortality, while no significant association was observed for cardiovascular (HR, 1.06 [0.99–1.14]; $P=0.105$) mortality. When never-smokers and ever-smokers were examined separately, the associations of cooking with clean fuels with mortality risks appeared to be more pronounced among never-smokers than among ever-smokers (Table 2). Among those cooking with clean fuels, lower risks of all-cause and cardiovascular mortality were observed among never-smokers reporting cooking on daily or weekly basis, when stratified by cooking frequency, although the associations were weaker among those who cooked weekly (Supplementary Table 2).

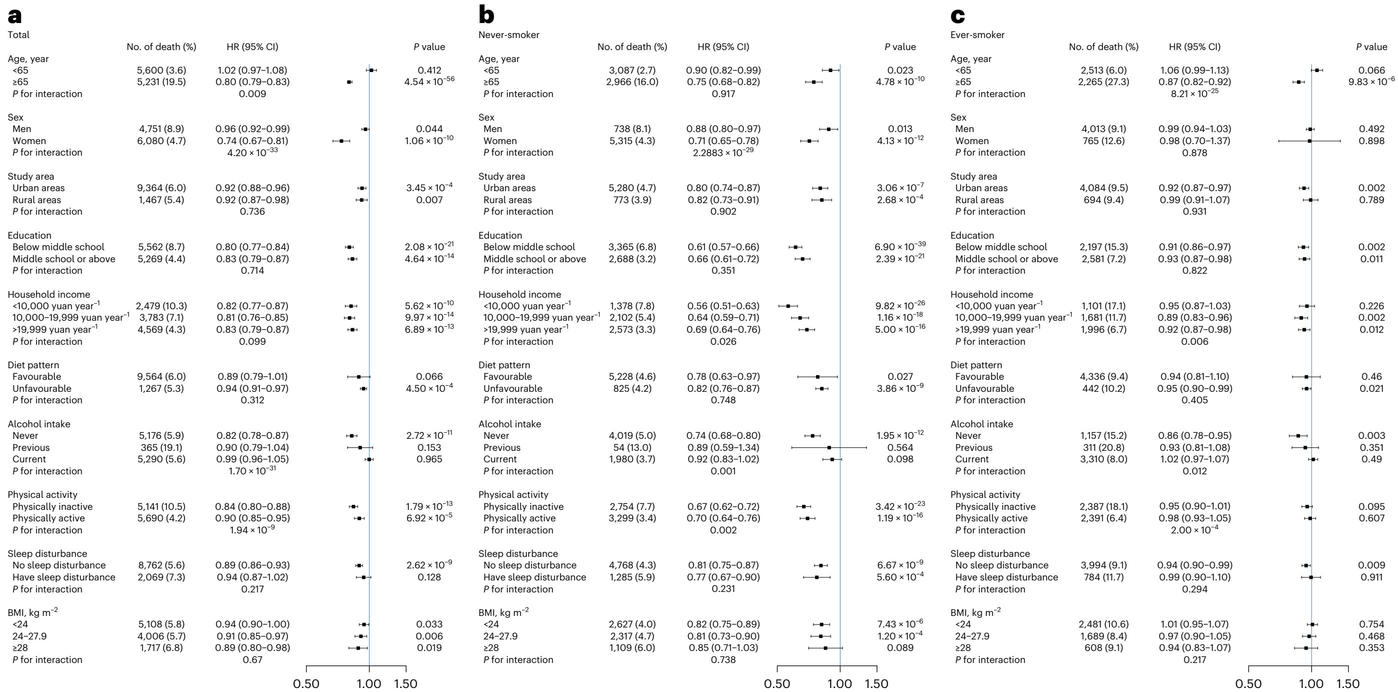

Fig. 3 | Association between cooking with clean fuels and all-cause mortality, stratified by baseline characteristics. a–c, Cox regression was used to estimate the HRs and 95% CIs for total participant (**a**; $n = 315{,}117$), never-smoker (**b**; $n = 163{,}351$) and ever-smoker (**c**; $n = 151{,}766$) with stratification according to age-at-risk, sex and study area and adjustment for education level, occupation, household income, smoking status (when appropriate), alcohol intake, passive smoking, physical activity, BMI, major chronic diseases at baseline and heating with solid fuels. The effect estimates represent the HRs from the Cox regression and the error bars represent 95% CIs. All statistical tests were two-sided. $P < 0.002$ was considered significant.

Participants reporting longer duration of cooking with clean fuels had lower risks of all-cause mortality, with the HRs of 0.94 (0.89–0.99; $P = 0.024$), 0.93 (0.88–0.97; $P = 0.002$) and 0.88 (0.84–0.92; $P = 6.83 \times 10^{-8}$), respectively, among those reporting <15, 15–25 and >25 years of cooking with clean fuels compared with those non-cooking (HR for trend, 0.96 [0.94–0.97], $P_{trend} = 2.42 \times 10^{-8}$; Fig. 2a). The corresponding HRs were 0.90 (0.82–0.99; $P = 0.027$), 0.85 (0.78–0.93; $P = 2.97 \times 10^{-4}$) and 0.83 (0.77–0.89; $P = 1.40 \times 10^{-6}$) for cardiovascular mortality (HR for trend, 0.94 [0.91–0.96], $P_{trend} = 3.73 \times 10^{-7}$; Fig. 2b) and 0.88 (0.73–1.06; $P = 0.184$), 0.89 (0.74–1.07; $P = 0.206$) and 0.87 (0.75–1.02; $P = 0.083$) for respiratory mortality (HR for trend, 0.94 [0.90–0.99], $P_{trend} = 0.026$; Fig. 2c). When further stratified by smoking status, the associations of all-cause and cardiovascular mortality were stronger among never-smokers than among ever-smokers, with the lowest HRs of 0.74 (0.68–0.80; $P = 1.20 \times 10^{-13}$) for all-cause mortality and 0.62 (0.55–0.71; $P = 3.15 \times 10^{-12}$) for cardiovascular mortality among never-smokers reported over 25 years of cooking with clean fuels. Sensitivity analyses using weighted duration achieved similar decreasing trends of all-cause and cardiovascular mortality with extended duration of cooking with clean fuels (Supplementary Fig. 1). When stratified by sex and smoking status, the dose–response relation between cooking with clean fuels and risk of all-cause and cardiovascular mortality remained significant among both male and female never-smokers (Supplementary Fig. 2).

The association between cooking with clean fuels and risk of all-cause mortality was stronger among women (HR, 0.74 [0.67–0.81], $P = 1.06 \times 10^{-10}$; HR for interaction, 0.74 [0.71–0.78], $P_{interaction} = 4.20 \times 10^{-33}$), never-drinkers (HR, 0.82 [0.78–0.87], $P = 2.72 \times 10^{-11}$; HR for interaction, 1.09 [1.07–1.10], $P_{interaction} = 1.70 \times 10^{-31}$) and among physically inactive participants (HR, 0.84 [0.80–0.88], $P = 1.79 \times 10^{-13}$; HR for interaction, 1.09 [1.06–1.12], $P_{interaction} = 1.94 \times 10^{-9}$) than their counterparts. Moreover, the risk of all-cause mortality appeared to be more extreme among ever-smokers aged 65 years or more (HR, 0.87 [0.82–0.92], $P = 9.83 \times 10^{-6}$; HR for interaction, 1.20 [1.16–1.24], $P_{interaction} = 8.21 \times 10^{-25}$) (Fig. 3). For cardiovascular mortality, the association was more obvious among women (HR, 0.60 [0.52–0.70], $P = 2.95 \times 10^{-11}$; HR for interaction, 0.62 [0.57–0.67], $P_{interaction} = 1.29 \times 10^{-29}$) and never-drinkers (HR, 0.73 [0.66–0.80], $P = 3.47 \times 10^{-11}$; HR for interaction, 1.11 [1.08–1.13], $P_{interaction} = 2.65 \times 10^{-18}$) (Supplementary Fig. 3).

Mediation and sensitivity analyses

In the mediation analysis, household physical activity explained 66.0% (38.5–85.8%), 58.1% (34.6–78.4%) and 50.1% (14.5–85.6%), respectively, of the decreased risks of all-cause and cardiopulmonary mortality associated with cooking with clean fuels. To a much less extent, favourable diet (1.3% [0.6–2.8%] to 1.5% [0.8–2.9%]) also accounted for the decreased risk of all-cause and cardiovascular mortality. Less than 1% of the mediation proportion was observed for other potential mediators (Fig. 4).

The findings remained largely similar in the sensitivity analyses of pooling area-specific results by random-effects meta-analysis (Supplementary Fig. 4), extended adjustment and further exclusions (Supplementary Table 3). The findings in the propensity score-matched population were more obvious for cooking with clean fuels and cooking with solid fuels, while less precise for switching from cooking to non-cooking, than those of the overall population (Supplementary Table 4).

Discussion

In this prospective cohort study involving 510,106 Chinese adults, after an average of 9.9 years of follow-up, a significantly lower risk of all-cause and cardiopulmonary mortality was seen among adults reporting cooking with clean fuels versus non-cooking and the risk decreased with extended years of cooking with clean fuels. These associations were more pronounced among never-smokers than among ever-smokers. Our study examined cooking in association with future risks of all-cause

https://doi.org/10.1038/s41562-022-01486-5

	HR (95% CI)	*P* value	Mediation proportion (95% CI)
a All-cause mortality			
Basic adjustment	0.90 (0.87–0.93)	1.39×10^{-9}	–
Lifestyle factors			
Household physical activity	0.96 (0.92–0.99)	0.029	66.0% (38.5%–85.8%)
Favourable diet	0.90 (0.86–0.93)	2.10×10^{-7}	1.5% (0.8%–2.9%)
Physiological factors			
Systolic blood pressure	0.90 (0.87–0.93)	2.32×10^{-10}	<1%
Random plasma glucose	0.90 (0.87–0.93)	2.28×10^{-9}	<1%
Psychological factors			
Life satisfaction level	0.90 (0.87–0.93)	2.42×10^{-10}	<1%
Major depression	0.90 (0.86–0.93)	3.21×10^{-10}	<1%
b Cardiovascular mortality			
Basic adjustment	0.83 (0.78–0.87)	6.83×10^{-11}	–
Lifestyle factors			
Household physical activity	0.93 (0.86–0.99)	0.043	58.1% (34.6%–78.4%)
Favourable diet	0.83 (0.78–0.89)	5.47×10^{-8}	1.3% (0.6%–2.8%)
Physiological factors			
Systolic blood pressure	0.82 (0.78–0.87)	4.31×10^{-11}	<1%
Random plasma glucose	0.83 (0.77–0.87)	4.81×10^{-12}	<1%
Psychological factors			
Life satisfaction level	0.82 (0.77–0.87)	1.16×10^{-11}	<1%
Major depression	0.82 (0.77–0.87)	1.48×10^{-11}	<1%
c Respiratory mortality			
Basic adjustment	0.88 (0.79–0.99)	0.026	–
Lifestyle factors			
Household physical activity	0.91 (0.79–1.05)	0.194	50.1% (14.5%–85.6%)
Favourable diet	0.89 (0.79–0.99)	0.043	<1%
Physiological factors			
Systolic blood pressure	0.89 (0.80–0.99)	0.032	<1%
Random plasma glucose	0.89 (0.80–0.99)	0.032	<1%
Psychological factors			
Life satisfaction level	0.88 (0.79–0.99)	0.026	<1%
Major depression	0.89 (0.79–0.99)	0.032	<1%

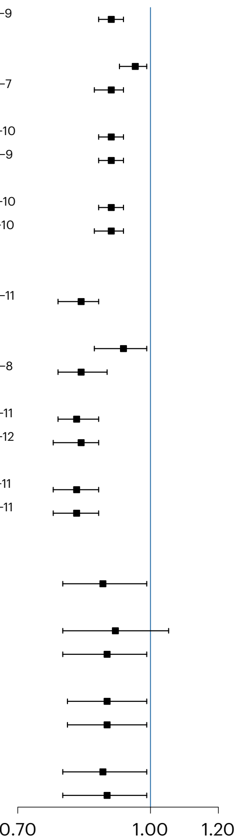

Fig. 4 | Estimated proportion of association between cooking with clean fuels and risk of all-cause and cardiopulmonary mortality explained by hypothesized mediators. a–**c**, Cox regression was used to estimate the HRs and 95% CIs for all-cause mortality (**a**; $n = 315{,}117$), cardiovascular mortality (**b**; $n = 315{,}117$) and respiratory mortality (**c**; $n = 315{,}117$) with stratification according to age-at-risk, sex and study area and adjustment for education level, occupation, household income, smoking status (when appropriate), alcohol intake, passive smoking, physical activity, BMI, major chronic diseases at baseline and heating with solid fuels in basic model. HRs of additional model additionally adjusted the hypothesized mediator. The effect estimates represent the HRs from the Cox regression and the error bars represent 95% CIs. All statistical tests were two-sided. $P < 0.05$ was considered significant. The proportion mediated is the percentage of the total exposure–outcome association that is attributed to the hypothesized mediator.

and cardiopulmonary mortality and showed that appreciably reduced mortality risks might be gained only when cooking with the usage of clean fuels.

One prospective study[19] to date has reported an inverse association of cooking with mortality, although the magnitude of benefits differed considerably. This study of 1,888 older adults from Taiwan with 10 years of follow-up found those cooking more than five times per week experienced a 41% lower mortality risk as compared with those in the non-cooking group. However, this study did not detect significant associations among those who cooked one to five times per week, perhaps due to the small sample size. Besides, information on the association of cooking with cause-specific mortality remained unclear, especially for cardiovascular mortality, which is the leading cause of mortality worldwide[20,21]. Involving 510,106 adults from five urban and five rural areas, we found a range of 10%–17% reduction in risks of all-cause mortality and cardiopulmonary mortality related to cooking with clean fuels versus non-cooking; whereas cooking with solid fuels was associated with higher risk of all-cause mortality, which is in line with our previous findings[8,9]. In particular, we found that the inverse association between cooking with clean fuels and mortality risks could be partly explained by increased household physical activity and favourable diet. Furthermore, we observed a decreasing trend in mortality risk with extended years of cooking with clean fuels, supporting a cumulative benefit of long-term cooking with clean fuels for mortality prevention.

In addition, we detected a higher mortality risk among those who had previously switched from cooking to non-cooking. The excess risk might partly be due to reverse causality[22,23], since a proportion of participants who had switched from cooking to non-cooking previously might stop cooking because of worsening health. Although the present study lacked detailed information on the specific reason for stopping, the prevalences of baseline cardiovascular disease (8.6% versus 4.3%), cancer (0.9% versus 0.4%) and poor self-rated health (14.8% versus 8.7%) among participants who cooked previously were approximately twice as those who had been always non-cooking. Exclusion of pre-existing chronic diseases significantly attenuated the association, which further supported the hypothesis that the excess risk associated with switching from cooking to non-cooking might partly be due to reverse causality.

Notably, the present study found that cooking with clean fuels might favour women more than men, which was consistent with the Taiwan study[19]. The observed gender difference might partly be explained through psychological pathways[24–26]. Nowadays, cooking is still primarily linked to the traditional expectation that women take the responsibility of preparing meals for their families to properly fulfil their wife or mother role[27]. Therefore, when undertaking cooking, men were more likely to suffer from psychosocial stress than women since it might be viewed as a threat to masculine identity[24–26], thereby offsetting the benefits from cooking with clean fuels[28]. The more extreme associations we observed among never-drinkers might be attributed to the much lower prevalence of alcohol intake among women than men (36.4% versus 79.6%). Furthermore, our findings suggested that cooking might lower mortality risk partly through increasing levels of household physical activity and stronger inverse associations were seen among physically inactive participants than their active counterparts. Except that cooking is a physically demanding activity itself[29], obtaining fresh ingredients for cooking usually requires more frequent food shopping, which then stimulates physical activity and adds weight-bearing exercise. Therefore, regular participation in cooking might be an effective alternative to meet daily physical activity requirement, especially for women among whom the prevalence of physical inactivity was generally high[30].

The present study also observed potential effect modification by age. It appeared that in ever-smokers aged <65 years, cooking with clean fuels was associated with higher mortality risk. Several factors might account for this observation. One possible explanation was the magnified adverse effects of inhaled air pollutants on respiratory system. The greater minute ventilation among younger participants would result in higher levels of exposure, especially when exposed to cooking oil fume and cigarette smoke jointly, therefore masking the benefits from cooking with clean fuels[31,32]. Besides, participants aged <65 years reported almost twice the levels of physical activity of those aged 65 years or more (22.7 versus 11.7 MET-hr d^{-1}) in the present study, thus might be less sensitive to benefits brought by regular cooking with clean fuels.

Our study uses a prospective design, has a relatively large sample size, includes participants from ten geographically diverse areas and uses detailed information on cooking behaviour that allows separation of participants switching from non-cooking to cooking. The large sample size also allows us to explore cooking frequency and types of fuels and perform subgroup analyses with sufficient power. Moreover, we reported a decreasing trend in mortality risk with extended duration of cooking with clean fuels, as well as an elevated risk among participants who have switched from cooking to non-cooking.

This study is subject to several limitations. A major limitation of the study was the lack of information on the assessment of overall diet quality. Nevertheless, our findings remained the same after additional adjustment for major food components in Chinese diet, which was expected to partially address the diet confounding. Second, measurement errors in self-reported assessments are inevitable. However, good reproducibility (kappa = 0.66) was seen when comparing cooking data at baseline and resurvey and the random measurement error was more likely to bias the observed association towards the null[33]. Third, our reliance on baseline assessment of cooking might not represent the cooking status during follow-up. However, we excluded participants who reported changing their cooking status in the resurvey and the results remained unchanged. Furthermore, due to the lack of information, we did not extend analyses on social factors such as social interactions, which have been related to cooking practice[3]. Future studies are still warranted to examine how social factors affect the association between cooking and mortality. Finally, despite extensive adjustment for potential confounders in this study, residual confounding remains likely. However, a propensity-based method was used to achieve balanced characteristics between comparison groups and the consistent results in the matched and overall population further indicated the robustness of our findings.

On the basis of a nationwide prospective cohort of Chinese adults, cooking with clean fuels was significantly associated with lower mortality risks, especially among never-smokers. These findings provided further evidence to suggest that cooking with clean fuels should be targeted as an important activity in future public health strategies to reduce mortality burden.

Methods

Study population

During June 2004 and July 2008, the CKB study enroled 512,715 adults aged 30–79 years from ten geographically diverse study areas (five urban and five rural areas; Fig. 1) across China and followed them to December 2018. At baseline and subsequent resurvey in ~4% random subset (n = 19,786) from July to October 2008, detailed information on sociodemographic characteristics, lifestyle factors, cooking behaviour and physical measurements was collected following standard procedures[33–36]. We excluded 2,609 study participants reporting unspecified cooking fuels and 510,106 participants were left in the current study (Fig. 1).

Assessment of cooking-related variables

In the present study, cooking was defined as the practices for preparing meals at home with the use of cooking stove[8,9]. At baseline and resurvey, all participants provided information about their cooking behaviours including frequency, primary fuel use and residence years up to three most recent residences (obtain the detailed questionnaire at https://www.ckbiobank.org/study-resources/survey-data). Participants were first asked how often they cooked at home in the present/previous/before previous house (single choice allowed; daily, weekly, monthly, never/rarely and no cooking facility) and those who cooked at least monthly were asked to provide the primary cooking fuel used (single choice allowed; gas, electricity, coal, wood and other unspecified fuels). Participants who reported a daily or weekly basis of cooking at least in the current residence were defined as 'always cooking' and we further categorized them into two groups as always cooking with clean fuels (gas and electricity) and always cooking with solid fuels (coal and wood), on the basis of previous evidence that solid fuels generated much more pollutants[37] and were associated with higher mortality risk[5–7]. Previous evidence[38] has reported that smokers were more likely to quit smoking because of health issues; we assumed that participants who cooked previously but changed to non-cooking might share the same reason, therefore we further categorized those who cooked monthly or less at baseline into 'cooking to non-cooking' and 'always non-cooking' according to whether they reported cooking in previous residence(s). However, we did not examine participants who reported non-cooking previously but changed to cooking separately because they have cooked for an average 24.4 years and shared similar mortality risks with those always cooking (Supplementary Table 5).

Because it has been several decades since global efforts on transition towards usage of clean fuels, the present study had a prespecified goal to explore if there is a long-term effect of cooking with clean fuels on mortality risk. We calculated self-reported total years lived in each residence during which clean fuels were used as the primary cooking fuel as duration of cooking with clean fuels. For more accurate approximation of long-term cooking with clean fuels, we conducted a sensitivity analysis by calculating weighted duration of cooking with clean fuels. We first assigned a weight coefficient to each cooking frequency group, namely 0.5 to 'weekly' and 1.0 to 'daily', and then multiplied the self-reported years of cooking with clean fuels by the assigned weight coefficient.

Ascertainment of deaths

We ascertained vital status by linking local Disease Surveillance Point system death registries and residential records until December 2018 (ref. [39]). We evaluated mortality from all causes (ICD-10 codes 001-999)[40] as well as mortality from cardiovascular diseases (I00-I25, I27-I88 and I95-I99) and respiratory diseases (J00-J99).

Statistical analyses

Baseline characteristics of 510,106 participants are described as medians with IQRs because all continuous variables did not meet the assumption of normality or percentages by categories of cooking. Among participants who have full information on cooking at both baseline and resurvey, the reproducibility of cooking status was assessed using simple kappa statistic[41]. Cox regression models were used to yield HRs and 95% CIs for all-cause and cardiopulmonary mortality in relation to cooking (including non-cooking to cooking, always cooking with clean fuels and always cooking with solid fuels) as compared with non-cooking, with stratification by age-at-risk (5 years), sex and study area and adjustment for established risk factors of mortality (including smoking status, passive smoking, alcohol intake, BMI (two missing values were replaced by the sex-specific median of BMI)) and physical activity level (including occupational, transportation and leisure-time physical activities; metabolic equivalent of tasks-hr d^{-1} (MET-hr d^{-1}), socioeconomic factors (including education, occupation and household income), major chronic diseases (including coronary heart disease, stroke, transient ischaemic attack, chronic obstructive pulmonary disease (COPD) and cancer at baseline) and heating solid fuel use. The Schoenfeld residuals were estimated to test the proportional hazards assumption[42] and the main exposure in all Cox regression models satisfied the assumption.

The associations of long-term cooking with clean fuels with risk of all-cause and cardiopulmonary mortality were examined by the comparison of <15, 15–25 and 25+ years of cooking with clean fuels (cut-offs rounded from the average tertiles of 16.5 years and 27.0 years for unweighted and weighted duration of cooking with clean fuels) with always non-cooking. Sensitivity analyses were conducted by weighted duration of cooking with clean fuels using the weights as previously described in exposure assessment. The HRs (95% CIs) and *P* values for trend were obtained through entering each cooking group as a continuous variable in the Cox regression models.

We also conducted prespecified subgroup analyses by age, sex, study area, education, household income, alcohol intake, diet pattern (favourable diet was defined as daily consumption of fresh vegetable and fruit and non-daily consumption of meat according to a 2013 guideline from the American Heart Association and the American College of Cardiology on lifestyle management to lower cardiovascular risk)[43], physical activity (physically active was defined as reporting 10 MET-hr $week^{-1}$ or more according to World Health Organization (WHO) physical activity recommendations), sleep disturbance (defined as reporting disorders of initiating and maintaining sleep, early morning awakening or having daytime dysfunction)[44] and BMI to account for potential modifying effect of each variable. The interaction term between each examined potential effect modifier and the exposure was further added in the Cox regression models in addition to the indicators of the two items to obtain the HRs (95% CIs) and *P* values for interaction.

On the basis of previous evidence suggesting that cooking may influence lifestyle[45], physiological[17,46,47] and psychological[48] factors, we further conducted mediation analyses to assess whether selected factors including household physical activity (h $week^{-1}$; defined as all physical activities spent on household chores, including cleaning, laundry, cooking and caring for other people at home), diet pattern, systolic blood pressure (mmHg), random plasma glucose (mmol l^{-1}), life satisfaction (satisfied with life was defined by the report of 'being satisfied' or 'very satisfied' with life) and major depression (major depression was defined by the WHO Composite International Diagnostic Interview-Short Form (CIDI-SF) diagnostic criteria of major depressive episode) may explain the associations between cooking with clean fuels and mortality risk. An SAS macro developed by Spiegelman et al. was used to estimate the proportion of associations between cooking with clean fuels and mortality risk that was attributable to the hypothesized mediators (http://www.hsph.harvard.edu/donna-spiegelman/software/mediate/)[49].

Six sensitivity analyses were performed to examine the robustness of our HR estimates: (1) calculating HRs by multilevel Cox regression separately within each study area followed by random-effects meta-analysis; (2) extended adjustment for survey season, diet factors (consumption of rice, wheat, other staples, meat, poultry, fish, eggs, fresh vegetables, soybeans, preserved vegetables, fresh fruits and dairy products), family history of cardiovascular disease and self-rated health because they could be potential confounders; (3) excluding participants reporting major chronic diseases at baseline because those participants might quit cooking owing to existing diseases; (4) excluding those who died within the first 2 years of follow-up to address reverse causation; (5) excluding participants reporting living in the present house for <5 years to scrutinize the possible effect of different cooking status in the previous residence(s) on mortality risk; (6) excluding participants reporting changing their cooking status during follow-up.

On the assumption that propensity-score matching might provide more effective control regarding confounders than adjustment did, we conducted a propensity score-matched analysis by including as many baseline variables that might have affected cooking behaviour as possible in the propensity score model to reduce selection bias, including age, sex, urban residence, education, occupation, household income, smoking status, passive smoking, alcohol intake, physical activity, major chronic diseases at baseline and BMI. We then calculated a propensity score for each participant and participants were matched one-to-one without replacement using a nearest-neighbour approach with a caliper width of 0.20 standard deviations[50]. The propensity score estimation and matching were done for each group separately. Standardized differences were assessed to ensure balance after propensity score matching between the comparison groups and <0.10 of between-group difference was considered to be well balanced[51]. All standardized differences in baseline covariates between the matched groups were <0.10 except for sex (only for always cooking with clean fuels) and urban residence (for cooking to non-cooking and always cooking with clean fuels), which were further adjusted in the Cox regression models[52].

All *P* values were two-sided and we defined statistical significance as $P < 0.05$ except for the subgroup analyses, in which the statistical significance was set at $P < 0.002$ (0.05/(ten subgroups × three outcomes)) to account for type I error because of the large number of tests being performed. All analyses were performed using SAS v.9.4 (SAS Institute) and graphs were plotted using R v.3.4.2 (R Foundation).

Ethical approval

Ethical approval was obtained from relevant international, national and local ethics committees. All participants gave written informed consent.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The authors do not own the data for this study. Data from the baseline survey, first resurvey and cause-specific mortality are available to all bona fide researchers (www.ckbiobank.org). Requests for additional data should be submitted to the (CKB) Data Access Committee (http://www.ckbiobank.org/site/Research/Data+Access+Policy). As stated in the policy, the CKB study group must maintain the integrity of the database for future use and regulate data access to comply with prior conditions agreed with the Chinese government. Data security is an integral part of CKB study protocols. Data can be released outside the CKB research group only with appropriate security safeguards.

Code availability

Analysis code is available at the Open Science Foundation repository at https://osf.io/ej7sd/.

References

1. Panwar, N. L., Kaushik, S. C. & Kothari, S. State of the art of solar cooking: an overview. *Renew. Sust. Energ. Rev.* **16**, 3776–3785 (2012).
2. Engler-Stringer, R. Food, cooking skills, and health: a literature review. *Can. J. Diet. Prac. Res.* **71**, 141–145 (2010).

3. Mills, S. et al. Health and social determinants and outcomes of home cooking: a systematic review of observational studies. *Appetite* **111**, 116–134 (2017).
4. Daniels, S., Glorieux, I., Minnen, J. & van Tienoven, T. P. More than preparing a meal? Concerning the meanings of home cooking. *Appetite* **58**, 1050–1056 (2012).
5. Du, W. et al. PAHs emissions from residential biomass burning in real-world cooking stoves in rural China. *Environ. Pollut.* **267**, 115592 (2020).
6. Chafe, Z. A. et al. Household cooking with solid fuels contributes to ambient $PM_{2.5}$ air pollution and the burden of disease. *Environ. Health Perspect.* **122**, 1314–1320 (2014).
7. Zhao, B. et al. Change in household fuels dominates the decrease in $PM_{2.5}$ exposure and premature mortality in China in 2005–2015. *Proc. Natl Acad. Sci. USA* **115**, 12401–12406 (2018).
8. Yu, K. et al. Cooking fuels and risk of all-cause and cardiopulmonary mortality in urban China, a prospective cohort study. *Lancet Glob. Health* **8**, e430–e439 (2020).
9. Yu, K. et al. Association of solid fuel use with risk of cardiovascular and all-cause mortality in rural China. *J. Am. Med. Assoc.* **319**, 1351–1361 (2018).
10. Gordon, S. B. et al. Respiratory risks from household air pollution in low- and middle-income countries. *Lancet Respir. Med.* **2**, 823–860 (2014).
11. Shupler, M. et al. Household and personal air pollution exposure measurements from 120 communities in eight countries: results from the PURE-AIR study. *Lancet Planet. Health* **4**, e451–e462 (2020).
12. *Tracking SDG 7: The Energy Progress Report* (IEA Press, 2020).
13. Lewis, J. J. & Pattanayak, S. K. Who adopts improved fuels and cookstoves? A systematic review. *Environ. Health Perspect.* **120**, 637–645 (2012).
14. Duan, X. et al. Household fuel use for cooking and heating in China, results from the first Chinese Environmental Exposure-Related Human Activity Patterns Survey (CEERHAPS). *Appl. Energ.* **136**, 692–703 (2014).
15. Zong, G., Eisenberg, D. M., Hu, F. B. & Sun, Q. Consumption of meals prepared at home and risk of type 2 diabetes, an analysis of two prospective cohort studies. *PLoS. Med.* **13**, e1002052 (2016).
16. Wang, F. et al. Associations between daily cooking duration and the prevalence of diabetes and prediabetes in a middle-aged and elderly Chinese population: a cross-sectional study. *Indoor Air* **28**, 238–246 (2018).
17. Zhang, Y., Tang, T. & Tang, K. Cooking frequency and hypertension with gender as a modifier. *Nutr. J.* **18**, 79 (2019).
18. Tani, Y., Fujiwara, T., Isumi, A. & Doi, S. Home cooking is related to potential reduction in cardiovascular disease risk among adolescents, results from the A-CHILD study. *Nutrients* **12**, 3845 (2020).
19. Chen, R. C., Lee, M., Chang, Y. H. & Wahlqvist, M. L. Cooking frequency may enhance survival in Taiwanese elderly. *Public Health Nutr.* **15**, 1142–1149 (2012).
20. GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019, a systematic analysis for the Global Burden of Disease Study 2019. *Lancet* **396**, 1204–1222 (2020).
21. He, J. et al. Major causes of death among men and women in China. *N. Engl. J. Med.* **353**, 1124–1134 (2005).
22. Flegal, K. M., Graubard, B. I., Williamson, D. F. & Cooper, R. S. Reverse causation and illness-related weight loss in observational studies of body weight and mortality. *Am. J. Epidemiol.* **173**, 1–9 (2011).
23. Hu, Y. et al. Smoking cessation, weight change, type 2 diabetes, and mortality. *N. Engl. J. Med.* **379**, 623–632 (2018).
24. Méjean, C. et al. Social disparities in food preparation behaviors, a DEDIPAC study. *Nutr. J.* **16**, 62 (2017).
25. Szabo, M. Foodwork or foodplay? Men's domestic cooking, privilege and leisure. *Br. J. Sociol.* **47**, 623–638 (2013).
26. Neuman, N., Gottzén, L. & Fjellström, C. Masculinity and the sociality of cooking in men's everyday lives. *Sociol. Rev.* **65**, 816–831 (2017).
27. Beagan, B., Chapman, G. E., D'Sylva, A. & Bassett, B. R. It's just easier for me to do it: rationalizing the family division of foodwork. *Sociology* **42**, 653–671 (2008).
28. Harryson, L., Aléx, L. & Hammarström, A. "I have surly passed a limit, it is simply too much", women's and men's experiences of stress and wellbeing when living within a process of housework resignation. *BMC Public Health* **16**, 224 (2016).
29. Lvarez-Gallardo, I. C. et al. Physical activity, sedentary behaviour, physical fitness, and cognitive performance in women with fibromyalgia who engage in reproductive and productive work: the al-Ándalus project. *Clin. Rheumatol.* **38**, 3585–3593 (2019).
30. Du, H. et al. Physical activity and sedentary leisure time and their associations with BMI, waist circumference, and percentage body fat in 0.5 million adults, the China Kadoorie Biobank study. *Am. J. Clin. Nutr.* **97**, 487–496 (2013).
31. Daigle, C. C. et al. Ultrafine particle deposition in humans during rest and exercise. *Inhal. Toxicol.* **15**, 539–552 (2003).
32. Tainio, M. et al. Air pollution, physical activity and health, a mapping review of the evidence. *Environ. Int.* **147**, 105954 (2021).
33. Hutcheon, J. A., Chiolero, A. & Hanley, J. A. Random measurement error and regression dilution bias. *Br. Med. J.* **340**, c2289 (2010).
34. Chen, Z. et al. China Kadoorie Biobank of 0.5 million people, survey methods, baseline characteristics and long-term follow-up. *Int. J. Epidemiol.* **40**, 1652–1666 (2011).
35. Chen, Z. et al. Cohort profile, the Kadoorie Study of Chronic Disease in China (KSCDC). *Int. J. Epidemiol.* **34**, 1243–1249 (2005).
36. Du, H. et al. Fresh fruit consumption and major cardiovascular disease in China. *N. Engl. J. Med.* **374**, 1332–1343 (2016).
37. Wang, S. & Luo, K. Life expectancy impacts due to heating energy utilization in China: distribution, relations, and policy implications. *Sci. Total. Environ.* **610–611**, 1047–1056 (2018).
38. Chen, Z. et al. Contrasting male and female trends in tobacco-attributed mortality in China: evidence from successive nationwide prospective cohort studies. *Lancet* **386**, 1447–1456 (2015).
39. Yang, G. et al. Rapid health transition in China, 1990–2010, findings from the Global Burden of Disease Study 2010. *Lancet* **381**, 1987–2015 (2013).
40. *The ICD-10 Classification of Mental and Behavioral Disorders, Diagnostic Criteria for Research* (WHO, 2021); https://www.who.int/classifications/icd/en/GRNBOOK.pdf
41. Landis, J. R. & Koch, G. G. The measurement of observer agreement for categorical data. *Biometrics* **33**, 159–174 (1977).
42. Grambsch, P. M. & Therneau, T. M. Proportional hazards tests and diagnostics based on weighted residuals. *Biometrika* **81**, 515 (1994).
43. Eckel, R. H. et al. 2013 AHA/ACC guideline on lifestyle management to reduce cardiovascular risk: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *J. Am. Coll. Cardiol.* **63**, 2960–2984 (2014).
44. Chair, S. Y. et al. Association between household solid fuel use for cooking and sleep disturbance in rural China: findings from the China Kadoorie Biobank data. *Sleep Med.* **83**, 13–20 (2020).
45. Wolfson, J. A., Leung, C. W. & Richardson, C. R. More frequent cooking at home is associated with higher Healthy Eating Index-2015 score. *Public Health Nutr.* **23**, 2384–2394 (2020).

46. Zong, G., Eisenberg, D. M., Hu, F. B. & Sun, Q. Consumption of meals prepared at home and risk of type 2 diabetes: an analysis of two prospective cohort studies. *PLoS. Med.* **13**, e1002052 (2016).
47. Duffey, K. J., Gordon-Larsen, P., Jacobs, D. R. Jr, Williams, O. D. & Popkin, B. M. Differential associations of fast food and restaurant food consumption with 3-y change in body mass index: the coronary artery risk development in young adults study. *Am. J. Clin. Nutr.* **85**, 201–208 (2007).
48. Shao, J., Ge, T., Liu, Y., Zhao, Z. & Xia, Y. Longitudinal associations between household solid fuel use and depression in middle-aged and older Chinese population: a cohort study. *Ecotoxicol. Environ. Saf.* **209**, 111833 (2021).
49. Lin, D. Y., Fleming, T. R. & De Gruttola, V. Estimating the proportion of treatment effect explained by a surrogate marker. *Stat. Med.* **16**, 1515–1527 (1997).
50. Seeger, J. D., Williams, P. L. & Walker, A. M. An application of propensity score matching using claims data. *Pharmacoepidemiol. Drug Saf.* **14**, 465–476 (2005).
51. Austin, P. C. Balance diagnostics for comparing the distribution of baseline covariates between treatment groups in propensity-score matched samples. *Stat. Med.* **28**, 3083–3107 (2009).
52. Kim, N. H., Han, K. H., Choi, J., Lee, J. & Kim, S. G. Use of fenofibrate on cardiovascular outcomes in statin users with metabolic syndrome: propensity matched cohort study. *Br. Med. J.* **366**, l5125 (2019).

Acknowledgements

This work, along with two previous publications[7,8] from our team, belongs to our project approved by the CKB study group (DAR-00081-CN). The members of the steering committee and collaborative group are listed in the Supplementary Information. This work was supported by grants from the National Natural Science Foundation of China (82192903, 82021005 and 81390540) (T.W.), the Fundamental Research Funds for the Central Universities (2019kfyXMBZ015) (T.W.) and the Consulting Project of Chinese Academy of Engineering (2022-XY-36) (T.W.). The CKB baseline survey and the first resurvey were supported by the Kadoorie Charitable Foundation in Hong Kong. The long-term follow-up has been supported by the UK Wellcome Trust (grant nos 088158/Z/09/Z and 104085/Z/14/Z) (Z.C.) and the National Key Research and Development Program of China (grants 2016YFC0900500, 2016YFC0900501 and 2016YFC0900504) (L.L.) and the Chinese Ministry of Science and Technology (2011BAI09B01) (L.L.). The British Heart Foundation, UK Medical Research Council and Cancer Research provide core funding to the Clinical Trial Service Unit and Epidemiological Studies Unit at Oxford University for the project. The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.

Author contributions

K.Y., L.L. and T.W. had the idea for the study and contributed to study design. Y.G., L.Y. and Y.C. coordinated data acquisition and standardization. K.Y. analysed data. K.Y., J.L., G.L., C.W. and T.W. interpreted data. K.Y. wrote the draft report and all authors contributed to revision of the report. J.L., C.Y., Y.G., L.Y., Z.C. and L.L. provided administrative, technical or material support. Z.C. and L.L. are members of the CKB study steering committee and designed and supervised overall study implementation and obtained funding.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41562-022-01486-5.

Correspondence and requests for materials should be addressed to Liming Li or Tangchun Wu.

Peer review information *Nature Human Behaviour* thanks Takeo Fujiwara, Ho Yu Cheng and Chloe Astbury for their contribution to the peer review of this work.

nature portfolio

Corresponding author(s): Tangchun Wu

Last updated by author(s): Oct 12, 2022

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our Editorial Policies and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☐	☒	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☐	☒	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☐	☒	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	No software was used.
Data analysis	All analyses were performed using SAS 9.4 (SAS Institute Inc, Cary, NC), and graphs were plotted using R 3.4.2 (R Foundation).

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

The authors do not own the data for this study. Copies of the CKB data on the baseline visit, first resurvey visit, and cause-specific mortality for the first 10 years of follow-up are available to any bona fide researchers (see: www.ckbiobank.org) and additional data on biochemical and genetic markers and non-fatal disease outcomes are available on a collaborative basis with CKB investigators. Requests for the data should be submitted to the CKB Data Access Committee (http://www.ckbiobank.org/site/Research/Data+Access+Policy). As stated in the policy, as data custodian, the CKB study group must maintain the integrity of the database for future use and regulate data access to comply with prior conditions agreed with the Chinese government. Data security is an integral part of CKB study protocols. Data can be released outside the CKB research group only with appropriate security safeguards.Analysis code is available at the Open Science Foundation repository at https://osf.io/ej7sd/.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Mixed-methods prospective cohort study
Research sample	The CKB study is set up to investigate the main genetic and environmental causes of common chronic diseases in the Chinese population, which took place in 10 geographically defined regions (5 urban and 5 rural) of China, chosen according to local disease patterns, exposure to certain risk factors, population stability, quality of death and disease registries, local commitment and capacity. Overall, of the 512 715 participants aged 30–79 years for the present analysis, 41% of the participants were men, 56% were from rural areas and the mean age was 52 years.
Sampling strategy	We did not predetermine the sample size and the CKB cohort is not designed to be representative of the general population in China. Despite this, the inclusion of an extremely large number of people from diverse populations should have enough power help to generate important new findings about the causes of many diseases that will be generalizable to other populations with different distribution of risk exposures. All eligible participants in each of 100–150 administrative units (rural villages or urban residential committees) randomly selected for the study within each region were identified through official residential records, and invitation letters (with study information leaflets) were delivered door-to-door by local community leaders or health workers, following extensive publicity campaigns.
Data collection	A Regional Coordinating Centre and survey team, consisting of about 15 full-time staff with medical qualifications and fieldwork experience, were established in each of the 10 study areas to collect data. No other person was presented besides the researchers and participants. At the baseline survey, detailed socio-demographic, lifestyle and medical data were collected using an interviewer-administered laptop-based questionnaire. The physical measurements included height, weight, hip and waist circumference (measuring tape), blood pressure (UA-779 digital monitor) and using standard instruments and protocols and with regular calibrations. For each participant, a 10-ml non-fasting blood sample was collected into one EDTA vacutainer (BD Hemogard™).
Timing	Baseline survey was conducted between June 2004 and July 2008.
Data exclusions	We excluded 2609 study participants reporting unspecified cooking fuels according to a pre-established criteria of excluding unreliable information on exposure assessment.
Non-participation	The study invited all participants aged 35-74 years to participate and the estimated population response rate was ~30% (26–38% in the five rural areas and 16–50% in the five urban areas). Overall, 515 681 people attended the baseline survey between June 2004 and July 2008, of whom 261 (0.05%) withdrew before completion, 2208 (0.4%) were found subsequently to have inadvertently attended the survey twice at different time points and 1 had major data errors.
Randomization	Not applicable in the present study because participants were not allocated to experimental groups.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology and archaeology
☒	☐	Animals and other organisms
☐	☒	Human research participants
☒	☐	Clinical data
☒	☐	Dual use research of concern

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging

Human research participants

Policy information about studies involving human research participants

Population characteristics	Overall, of the 512 715 participants aged 30–79 years (i.e. excluding 320 outside this age range) for the present analysis, 41% of the participants were men, 56% were from rural areas and the mean age was 52 years. The number recruited from each area ranged from about 30 000 in Haikou to over 63 000 in Henan.
Recruitment	Participants in CKB were recruited from 10 areas (5 urban/5 rural) in China in 2004-2008 with an overall response rate of 30%. We do not believe there is any self-selection bias that would impact the results because all eligible participants were equally invited and only 0.2% of the recruited participants were lost to follow-up by 1 January 2011.
Ethics oversight	This study was approved by the ethical review committee of the Chinese Center for Disease Control and Prevention (Beijing, China) and the Oxford Tropical Research Ethics Committee, University of Oxford (UK).

Note that full information on the approval of the study protocol must also be provided in the manuscript.