Cooking fuels and risk of all-cause and cardiopulmonary mortality in urban China: a prospective cohort study

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Summary

Background Cooking practice has transitioned from use of solid fuels to use of clean fuels, with addition of better ventilation facilities. However, the change in mortality risk associated with such a transition remains unclear.

Methods The China Kadoorie Biobank (CKB) Study enrolled participants (aged 30–79 years) from ten areas across China; we chose to study participants from five urban areas where transition from use of solid fuels to clean fuels for cooking was prevalent. Participants who reported regular cooking (weekly or more frequently) at baseline were categorised as persistent clean fuel users, previous solid fuel users, or persistent solid fuel users, according to self-reported fuel use histories. All-cause and cardiopulmonary mortality were identified through linkage to China’s Disease Surveillance Point system and local mortality records.

Findings Between June 24, 2004, and July 15, 2008, 226,186 participants living in five urban areas of China were enrolled in the CKB Study. Among 171,677 participants who reported cooking regularly (weekly or more frequently), 75,785 (44%) were persistent clean fuel users, 80,511 (47%) were previous solid fuel users, and 15,381 (9%) were persistent solid fuel users. During a mean of 9·8 (SD 1·7) years of follow-up, 10,831 deaths were documented, including 3819 cardiovascular deaths and 761 respiratory deaths. Cessation of solid fuel use was associated with lower all-cause mortality risk, even among persistent clean fuel users (HR 0·78, 0·69–0·89). Solid fuel use for cooking is associated with a higher risk of mortality, and cessation of solid fuel use cuts excess mortality risks swiftly and substantially within 5 years. Ventilation use also lowers the risk of mortality, even among people who persistently use clean fuels. It is of prime importance for both policy makers and the public to accelerate the transition from solid fuels to clean fuels and promote efficient ventilation to minimise further adverse health effects.

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Research in context

Evidence before this study
We searched PubMed, Web of Science, and Google Scholar up to Oct 24, 2019, with the keywords: (“cooking fuel” OR “solid fuel” OR “coal” OR “wood”) AND (“cessation” OR “switch” OR “transition”) AND (“mortality” OR “total death” OR “all-cause death” OR “cardiovascular mortality” OR “respiratory mortality”). We searched for articles and reviews with search terms in English, but we did not apply any language restrictions. Our search retrieved three prospective cohort studies that have assessed the association between cessation of solid fuel use and mortality risk. Two studies provided preliminary evidence that mortality risk was lower after cessation of solid fuel use, without examining the time course of risk reduction. In the third study of 74,941 women from Shanghai, mortality risk was investigated in association with cessation of coal use for fewer than 10 years, 10–20 years, and more than 20 years; a higher risk of ischaemic heart disease mortality was associated with cessation of coal use, with the risk falling with increasing years after cessation. However, no increased risk was noted for all-cause mortality and death from other causes, even among the group within 10 years of cessation, indicating that risk reduction could have occurred quickly after cessation and needed to be examined at finer time scales. If a substantial risk reduction was proven to occur within only a few years after cessation of solid fuel use, implementation of clean fuel initiatives would be prioritised and better motivated. Moreover, only about 1% of the participants in the Shanghai study were persistent coal fuel users, leading to an inaccurate estimate of the relative risk of cessation of coal use compared with persistent coal use. Moreover, none of the three studies investigated the associations separately among men and women, or the effect of ventilation on mortality risks among participants cooking with clean fuels.

Added value of this study
Our study, with nearly 10 years of follow-up, included 171,677 participants from five urban areas across China who reported that they cooked regularly. Our findings showed for the first time that the excess risks of all-cause and cardiopulmonary mortality from use of solid cooking fuels decreased by more than 60% at 5 years after cessation, and continued to decrease afterwards. Our study extends previous findings to men and women separately, and confirms similar results in both sexes on the relations between cessation of solid fuel use and mortality risks. Moreover, our study provides novel evidence that ventilation use is associated with lower mortality risks, even among people who use clean cooking fuels. To our knowledge, our study is the largest and most comprehensive study to date investigating the association of cooking fuel types, time since switching to clean fuels, and use of ventilation with risks of all-cause and cardiopulmonary mortality.

Implications of all the available evidence
Our findings underscore the importance of improving access to both clean fuels and ventilation to reduce global mortality burden from cooking fuel use. The greatest reductions in risks of mortality occurred within the first 5 years after cessation. 2·7 billion people are still using solid fuels for cooking globally; therefore, the transition from solid fuels to clean fuels, and use of ventilation, are likely to yield substantial environmental improvements and public health gains.

mortality risks. In that study, the risk of ischaemic heart disease mortality was reduced to the level of never-users of coal after more than 20 years of cessation. However, risks for all-cause mortality or deaths from other causes were not associated with cessation of coal use compared with never-use of coal, even among people within 10 years after cessation, indicating that the risk reduction could have occurred soon after cessation and needed to be examined at finer timescales. If a substantial risk reduction was proven to occur within only a few years after cessation of solid fuel use, implementation of clean fuel initiatives might be prioritised and better motivated. Moreover, the Shanghai study was restricted to women living in the most economically developed city in China, and only about 1% of participants were persistent coal users; therefore, the relative mortality risk for cessation of coal use compared with persistent coal use remains unclear. The effects on health of ventilation during cooking with fuel types other than solid fuels are also important to investigate. Mortality risks are diminished when ventilation is used, since even clean fuel is not entirely exempt from producing pollutants, such as fine particulate matter (PM$_{2.5}$). Using prospective data from the China Kadoorie Biobank (CKB) Study, we aimed to investigate associations between types of cooking fuel, time since switching to clean fuels, use of ventilation, and risks of all-cause and cardiopulmonary mortality.

Methods

Study design and population
Details of the CKB Study have been described elsewhere. Briefly, the CKB Study recruited participants (aged 30–79 years) from ten geographically diverse areas across China. Every participant answered a questionnaire administered by a trained interviewer, to gather information on sociodemographic characteristics, lifestyle factors, household air pollution exposures, and medical history. After completion of the baseline survey, a small proportion of participants was randomly chosen from the ten study areas and resurveyed to check the reproducibility of baseline information.

Because rural and urban populations in China have strikingly different energy use patterns and are at distinct phases of fuel use transition, we chose to focus our study on CKB Study participants from five urban areas...
(appendix p 8) where the transition from use of solid fuels to clean fuels for cooking was prevalent.

The CKB study was approved by the Oxford University Tropical Research Ethics Committee and the Chinese Center for Disease Control and Prevention Ethics Review Committee. All participants provided written informed consent.

Procedures
We gathered information from participants on cooking frequency, the primary fuel used for cooking, cookstove ventilation, and years lived in each of the three most recent residences. Among the primary cooking fuels reported, coal and wood were defined as solid fuels whereas gas and electricity were defined as clean fuels. Participants who reported cooking daily or weekly were further categorised according to their history of cooking fuel use before baseline, as either persistent users of clean fuel, previous users of solid fuel (participants who reported using clean fuel at baseline but used solid fuels in one or more previous residences), or persistent users of solid fuel. Among previous users of solid fuel, the time since cessation of solid fuel use was calculated by aggregating the time (in years) lived in consecutive residences during which time clean fuel was the primary cooking fuel, assuming that the primary fuel used for cooking had not changed during each residential period. We defined the people who cooked with ventilation as those whose cookstove in the present residence was equipped with a chimney or a kitchen exhaust fan.

We gathered information on all-cause and cardio-pulmonary mortality periodically (from baseline until Dec 31, 2016) through linkage to China’s Disease Surveillance Point system via each participant’s unique identification number, supplemented by the national health insurance system and annual active confirmation of survival obtained by local street committees and village administrators. The underlying cause of death was classified by trained staff who were unaware of baseline information, using the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10). The primary outcomes of our study were all-cause mortality (ICD-10 codes 001–999), cardiovascular disease mortality (I00–I09, I10–I15, and I20–I25), and respiratory disease mortality (J00–J99). Secondary endpoints were the main components of cardiopulmonary mortality, including ischaemic heart disease (I20–I25), stroke (I60–I64), ischaemic stroke (I63), haemorrhagic stroke (I61), chronic obstructive pulmonary disease (COPD; J41–J44), and pneumonia (J12–J18).

Statistical analysis
Baseline characteristics of the study population are presented as means with SDs or percentages, by type of cooking fuel use. The reproducibility of baseline information, including cooking fuel use, was assessed by intraclass correlation coefficients (ICC) for continuous variables and the weighted κ statistic for categorical variables, using repeated measures at baseline and in the resurvey (mean 2.5 [SD 0.6] years after baseline). Cox proportional-hazards regression models were used to estimate multivariate-adjusted hazard ratios (HRs) and 95% CIs of mortality risks associated with type of cooking fuel use, time since cessation of solid fuel use, and use of ventilation. We tested the proportional-hazard assumption using Schoenfeld residuals and found no evidence of departure from the assumption in models for all-cause mortality (p=0.079), cardiovascular mortality (p=0.081), and respiratory mortality (p=0.26).

We used the restricted cubic spline function in a stratified Cox model to inspect the change of mortality risk along with time since cessation of use of solid fuel, with the %LGTPHCURV9 macro in SAS version 9.4. We set three knots at the 5th, 50th, and 95th percentiles of the exposure variable (ie, time since cessation of solid fuel use) for the restricted cubic spline function, with no offset values for the fixed terms, resulting in two degrees of freedom (2 df). Non-linearity was examined by a likelihood ratio test, which compared two models with and without non-linear terms. We also did separate analyses among men and women and across subgroups of smoking status, considering the possible joint effect of smoking and solid fuel use on mortality risk. In all analyses, exposure variables were assessed using information on fuel use reported at baseline without considering any changes in fuel use during follow-up.

To test the robustness of our HR estimates of mortality risks associated with types of cooking fuel, we did five sensitivity analyses. First, we made further adjustments for conventional cardiovascular risk factors or other potential confounders. Second, we excluded participants with major diseases (including cardiovascular disease and cancer) at baseline. Third, we excluded participants who died within the first 2 years of follow-up, to scrutinise reverse causality; this analysis would look at the possibility that these participants had baseline subclinical diseases that could affect fuel choice. Fourth, we analysed coal use and wood use separately. Finally, we looked at specific causes of death, including ischaemic heart disease, stroke (and ischaemic and haemorrhagic subtypes of stroke), COPD, and pneumonia.

We judged two-sided p values less than 0.05 statistically significant. All analyses were done using SAS version 9.4. Graphs were plotted using R version 3.4.2. Model adjustments and other details about statistical analyses are provided in the appendix (p 3).

Role of the funding source
The funders had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding authors had full access to all data in
Baseline characteristics of study participants according to types of cooking fuel

| Overall (n=121 677) | Women (n=121 366) | Men (n=50 311) |
|----------------------|--------------------|-----------------|
|                      | Persistent clean fuel users (n=75 785) | Previous solid fuel users (n=80 511) | Persistent solid fuel users (n=15 381) | Persistent clean fuel users (n=47 077) | Previous solid fuel users (n=62 957) | Persistent solid fuel users (n=11 332) | Persistent clean fuel users (n=28 708) | Previous solid fuel users (n=17 554) | Persistent solid fuel users (n=40 409) |
| Age (years)          | 49.2 (10.1)        | 55.6 (9.9)      | 57.1 (10.6)     | 48.4 (9.6)        | 55.6 (9.9)      | 56.7 (10.8)     | 50.4 (10.8)        | 55.7 (9.8)      | 58.2 (10.2)     |
| Education            |                    |                  |                 |                    |                  |                 |                    |                  |                 |
| Primary school or lower | 12.0 (12%)        | 13.4 (11%)      | 11.4 (7%)       | 12.3 (13%)        | 13.4 (11%)      | 11.4 (7%)       | 12.3 (13%)        | 13.4 (11%)      | 11.4 (7%)       |
| Middle school        | 25.7 (24%)        | 26.1 (22%)      | 23.3 (19%)      | 25.2 (26%)        | 26.1 (22%)      | 23.3 (19%)      | 25.2 (26%)        | 26.1 (22%)      | 23.3 (19%)      |
| High school or higher | 38.6 (50%)        | 19.6 (24%)      | 9.7 (6%)        | 34.4 (50%)        | 19.6 (24%)      | 9.7 (6%)        | 34.4 (50%)        | 19.6 (24%)      | 9.7 (6%)        |
| Household income per year (¥)* |                |                  |                 |                    |                  |                 |                    |                  |                 |
| <20 000              | 28.6 (38%)        | 37.6 (42%)      | 10.5 (9%)       | 17.9 (38%)        | 30.4 (42%)      | 8.0 (9%)        | 16.1 (38%)        | 27.4 (42%)      | 8.1 (9%)        |
| 20 000–34 999        | 26.8 (35%)        | 24.9 (31%)      | 3.0 (7%)        | 16.4 (35%)        | 19.1 (31%)      | 3.0 (7%)        | 16.4 (35%)        | 19.1 (31%)      | 3.0 (7%)        |
| ≥35 000              | 20.4 (27%)        | 17.9 (22%)      | 1.7 (12%)       | 12.6 (27%)        | 13.3 (21%)      | 1.7 (12%)       | 12.6 (27%)        | 13.3 (21%)      | 1.7 (12%)       |
| Smoking category     |                    |                  |                 |                    |                  |                 |                    |                  |                 |
| Never-smoker         | 50.9 (67%)        | 62.3 (77%)      | 11.6 (76%)      | 45.4 (97%)        | 59.6 (95%)      | 11.0 (98%)      | 55.3 (99%)        | 72.7 (75%)      | 56.2 (14%)      |
| Former smoker        | 42.1 (6%)         | 38.1 (5%)       | 7.0 (9%)        | 18.2 (1%)         | 7.2 (1%)        | 4.1 (1%)        | 4.0 (1%)          | 3.9 (1%)        | 4.6 (1%)        |
| Current smoker       | 20.6 (27%)        | 14.3 (18%)      | 3.0 (20%)       | 14.6 (3%)         | 2.6 (2%)        | 3.0 (20%)       | 19.4 (27%)        | 11.7 (14%)      | 4.9 (16%)       |
| Physical activity (MET-h per day)† | 19.0 (11.5) | 17.9 (12.4) | 20.7 (13.9) | 18.2 (10.9) | 17.1 (11.6) | 19.7 (12.5) | 20.2 (12.4) | 20.9 (14.6) | 23.5 (17.0) |
| Body-mass index (kg/m²) | 24.4 (3.4)       | 24.6 (3.4)      | 22.9 (3.4)      | 24.2 (3.4)       | 24.6 (3.5)      | 23.0 (3.5)      | 24.7 (3.3)       | 24.3 (3.2)      | 22.8 (3.1)      |
| Waist circumference (cm) | 81.9 (9.9)       | 81.9 (9.9)      | 77.4 (9.9)      | 79.2 (9.2)       | 81.2 (9.5)      | 77.9 (9.4)      | 86.2 (9.4)       | 84.3 (9.6)      | 78.6 (9.6)      |
| Systolic blood pressure (mm Hg) | 126.3 (20.3) | 131.3 (21.4) | 132.0 (23.1) | 122.9 (20.3) | 130.5 (21.8) | 131.3 (23.7) | 131.8 (19.3) | 134.1 (19.8) | 139.3 (21.1) |
| Hypertension         | 21.3 (28%)        | 31.3 (29%)      | 56.2 (37%)      | 11.1 (24%)       | 32.8 (38%)      | 40.0 (35%)      | 10.2 (26%)       | 34.7 (42%)      | 69.2 (42%)      |
| Diabetes             | 52.3 (7%)         | 77.1 (10%)      | 7.2 (5%)        | 30.4 (6%)        | 65.1 (10%)      | 5.7 (5%)        | 22.8 (8%)        | 15.6 (9%)       | 205 (5%)       |
| Poor self-reported health† | 50.5 (7%)       | 85.8 (11%)      | 195.3 (13%)     | 32.3 (7%)        | 706.8 (11%)     | 150.2 (13%)     | 185.2 (6%)       | 151.1 (9%)      | 455 (11%)       |
| Passive smoking      | 42.2 (56%)        | 43.6 (56%)      | 896.5 (58%)     | 25.1 (53%)       | 33.4 (53%)      | 64.4 (57%)      | 17.1 (60%)       | 10.4 (60%)      | 295 (63%)       |
| Cookstove ventilation | 70.4 (93%)        | 71.8 (89%)      | 10.5 (69%)      | 43.7 (93%)       | 56.3 (89%)      | 75.8 (67%)      | 26.6 (93%)       | 55.8 (89%)      | 30.5 (75%)      |

Table 1: Baseline characteristics of study participants according to types of cooking fuel

Data (continuous variables) are mean (SD) or (categorical variables) percentages. *At the exchange rate as of November, 2019, ¥100 is approximately equal to US$£15. †MET-h per day=metabolic equivalent of task h per day. 1 MET-h is defined as 1 kcal/kg per h. ‡Participants were asked to rate their current general health status, with choices of excellent, good, fair, and poor.

the study and had final responsibility for the decision to submit for publication.

**Results**

Between June 25, 2004, and July 15, 2008, 512 891 adults from ten areas of China (five rural and five urban) completed the baseline questionnaire for the CKB Study and provided physical measurements. Between May 26, 2008, and Oct 10, 2008, 19 788 (4%) participants were randomly chosen for resurveying, to check the reproducibility of baseline information. By Dec 31, 2016, 4781 (1%) of 512 891 participants recruited to the CKB Study at baseline had been lost to follow-up, and 44 037 (9%) had died.

226 186 participants were enrolled from five urban areas of China. 179 participants were excluded from our study because the total duration of their three most recent residential periods was greater than their age; 54 317 participants were excluded because they did not cook regularly (monthly [n=9 126]; rarely or never [n=45 191]), and 74 participants were excluded because they used other unspecified fuels for cooking (appendix p 9).

171 677 (76%) participants reported cooking regularly (weekly or more frequently) at baseline, of whom 75 785 (44%) were persistent users of clean fuel, 80 511 (47%) were previous users of solid fuel, and 15 381 (9%) were persistent users of solid fuel (table 1). Among both men and women, previous and persistent solid fuel users were older and less educated, had lower household income and worse self-reported health status, and were less likely to use cookstove ventilation (table 1). Data for 8161 (4%) participants included in the resurvey are presented in the appendix (p 4). Baseline information,
including education level, household income, smoking, drinking, heating fuel use, ventilation status, physical activity and body-mass index, showed reasonable agreement with that reported or measured in the resurvey (ICC ≥0·74 for continuous variables; weighted κ values ≥0·43 for categorical variables). In particular, 6431 (79%) and 6594 (81%) participants in the resurvey reported the same cooking fuel use and ventilation use as at baseline, yielding weighted κ values of 0·56 and 0·55, respectively (appendix p 4).

Mean follow-up, defined as the time between the baseline examination and death or the censor date (Dec 31, 2016), was 9·8 (SD 1·7) years for the 171 baseline examination and death or the censor date respectively (appendix p 4).

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|                  | All-cause mortality | Cardiovascular mortality | Respiratory mortality |
|------------------|---------------------|--------------------------|----------------------|
|                  | Deaths (n)          | Hazard ratio (95% CI)    | Deaths (n)           | Hazard ratio (95% CI)    | Deaths (n) | Hazard ratio (95% CI)    |
| **Total**        |                     |                          |                      |                         |            |
| Persistent clean fuel users | 75 785 | 3608 | 1 (ref) | 1235 | 1 (ref) | 209 | 1 (ref) |
| Previous solid fuel users | 80 511 | 5752 | 0·97 (0·93–1·01) | 2081 | 0·98 (0·91–1·05) | 415 | 1·08 (0·90–1·29) |
| <5 years since cessation | 77 28 | 579 | 1·07 (1·01–1·14) | 193 | 1·12 (0·92–1·39) | 40 | 1·19 (0·91–1·57) |
| 5–10 years since cessation | 17 927 | 1184 | 1·03 (0·93–1·13) | 392 | 0·97 (0·86–1·09) | 80 | 1·11 (0·85–1·45) |
| >10 years since cessation | 54 856 | 3989 | 0·94 (0·89–1·01) | 1496 | 0·98 (0·90–1·06) | 295 | 1·09 (0·90–1·32) |
| Persistent solid fuel users | 15 381 | 1471 | 1·19 (1·10–1·28) | 503 | 1·24 (1·10–1·39) | 137 | 1·43 (1·10–1·85) |

**Women**

|                  | All-cause mortality | Cardiovascular mortality | Respiratory mortality |
|------------------|---------------------|--------------------------|----------------------|
|                  | Deaths (n)          | Hazard ratio (95% CI)    | Deaths (n)           | Hazard ratio (95% CI)    | Deaths (n) | Hazard ratio (95% CI)    |
| Persistent clean fuel users | 47 077 | 1335 | 1 (ref) | 410 | 1 (ref) | 66 | 1 (ref) |
| Previous solid fuel users | 62 957 | 3910 | 1·04 (0·97–1·11) | 1469 | 1·10 (0·98–1·23) | 250 | 0·98 (0·74–1·30) |
| <5 years since cessation | 58 67 | 362 | 1·10 (1·01–1·21) | 132 | 1·13 (0·92–1·40) | 21 | 1·17 (0·64–2·13) |
| 5–10 years since cessation | 13 803 | 785 | 1·05 (0·93–1·18) | 267 | 1·08 (0·92–1·27) | 41 | 0·87 (0·58–1·30) |
| >10 years since cessation | 43 187 | 2763 | 1·03 (0·94–1·08) | 1070 | 1·02 (0·88–1·22) | 188 | 0·98 (0·73–1·32) |
| Persistent solid fuel users | 11 332 | 876 | 1·25 (1·14–1·38) | 322 | 1·38 (1·17–1·62) | 77 | 1·40 (0·96–2·04) |

**Men**

|                  | All-cause mortality | Cardiovascular mortality | Respiratory mortality |
|------------------|---------------------|--------------------------|----------------------|
|                  | Deaths (n)          | Hazard ratio (95% CI)    | Deaths (n)           | Hazard ratio (95% CI)    | Deaths (n) | Hazard ratio (95% CI)    |
| Persistent clean fuel users | 28 708 | 2273 | 1 (ref) | 825 | 1 (ref) | 143 | 1 (ref) |
| Previous solid fuel users | 17 554 | 1842 | 0·94 (0·88–1·00) | 612 | 0·91 (0·82–1·02) | 165 | 1·10 (0·94–1·49) |
| <5 years since cessation | 18 61 | 217 | 1·03 (0·89–1·19) | 61 | 1·08 (0·83–1·34) | 19 | 1·25 (0·63–2·54) |
| 5–10 years since cessation | 41 244 | 399 | 0·97 (0·87–1·08) | 125 | 0·88 (0·73–1·07) | 39 | 1·36 (0·83–2·33) |
| >10 years since cessation | 11 569 | 1226 | 0·93 (0·86–1·00) | 426 | 0·90 (0·80–1·02) | 107 | 1·12 (0·87–1·46) |
| Persistent solid fuel users | 40 409 | 595 | 1·11 (1·00–1·22) | 181 | 1·16 (0·97–1·38) | 60 | 1·48 (1·06–2·05) |

Hazard ratios were derived from Cox models stratified by age at risk, sex (when appropriate), and study area and adjusted for education level, household income, alcohol consumption, smoking status, passive smoking, physical activity, body-mass index, diet (consumption of fresh fruit, preserved vegetables, and meat), cookstove ventilation, and solid fuel use for heating.

Table 2: Adjusted hazard ratios for all-cause and cardiopulmonary mortality by sex and type of cooking fuel.
0.97, 0.85–1.10; and 1.10, 0.83–1.45), equivalent to more than a 60% reduction in excess risk. Risks of mortality continued to decrease with time afterwards. Similar patterns were seen in both women and men in stratified analyses, except no rapid decreasing trend in risk for respiratory mortality was noted among men in the first 5 years, possibly attributable to the small number of respiratory deaths among men, which restricted statistical power to generate reliable risk estimates (table 2; figure 1). When stratified by smoking status, associations remained significant when analyses were restricted to female never-smokers (figure 2); no statistically significant differences
were noted in all-cause and cardiopulmonary mortality according to time since cessation of solid fuel use in male never-smokers and male ever-smokers. Female ever-smokers and male never-smokers were not analysed because of small sample sizes.

Participants cooking with ventilation had lower risks of all-cause mortality (HR 0.81, 95% CI 0.76–0.87) and cardiovascular mortality (0.75, 0.66–0.83) compared with those cooking without ventilation, and solid fuel use for heating. Line at 1.0 represents the reference category persistent clean fuel users and previous solid fuel users with >10 years of cessation, indicating participants who had reported always using clean fuels or switching from solid to clean fuels for >10 years. We only present results for female never-smokers (n=116 105; A–C) and male ever-smokers (n=41 506; D–F) because of the small sample size of female ever-smokers (n=5261) and male never-smokers (n=8805). Solid red lines show HR estimates and shaded areas show 95% CIs. HR=hazard ratio.

**Discussion**

The findings of our prospective cohort study of people from five geographically diverse urban areas in China showed that use of solid fuel for cooking was associated with higher risk of all-cause and cardiopulmonary mortality compared with use of clean fuel. Cessation of solid fuel use was associated with lower mortality risk, with substantial risk reduction achieved within 5 years after cessation. Moreover, ventilation was associated with lower mortality risk, even among persistent users of clean fuel. To our knowledge, our study is the largest to date to investigate associations of cooking fuel types, time since switching to clean fuels, and use of ventilation with the risk for all-cause and cardiopulmonary mortality. Findings of several prospective studies, including our previous study in rural China, have shown an increased mortality risk among users of solid fuel, which accord with our current study findings. Nevertheless, in the Prospective Urban and Rural Epidemiology (PURE) study of 91 350 participants (9.1 years of follow-up), when comparing solid fuel use versus clean fuel use in urban areas, no associations were seen for all-cause mortality (HR 1.12, 95% CI 0.96–1.31), cardiovascular mortality (HR 1.12, 95% CI 0.96–1.31), and respiratory mortality (HR 1.12, 95% CI 0.96–1.31).
Most previous studies have focused on mortality risks associated with current use of solid fuel. The association related to changes in mortality risk after cessation of solid fuel use remains largely uninvestigated. Two studies, both including participants in the CKB Study, with one focusing on rural areas and the other on never-smokers, provided evidence that the mortality risk was lower after cessation of solid fuel use. These two studies, however, did not look at when mortality risk began to decrease after cessation. Only one study of 74,941 women from Shanghai investigated mortality risks in association with time since cessation of coal use (<10 years, 10–20 years, and >20 years), and reported that the risk of ischaemic heart disease mortality was reduced with increasing years of cessation, whereas no such trend was seen for all-cause mortality and death from other causes.

By examining the association over a much finer timescale, our study has extended this previous research, and our findings showed that the excess risks of both all-cause and cardiopulmonary mortality among previous solid fuel users decreased by more than 60% at 5 years after cessation, and continued to decrease afterwards. The discrepant findings from the Shanghai study might be because only about 1% of participants were persistent users of solid fuel, and most had ceased use of coal at baseline. Moreover, inclusion of participants switching from coal use to non-cooking might bias the association, because those with pre-existing diseases were more likely to stop cooking but had higher mortality risks. Furthermore, as far as we know, we have shown for the first time a similar decreasing trend in mortality risk after switching to clean fuel use in both men and women. In summary, our findings underscore the urgency of transition from solid fuel use in both men and women.
fueled to clean fuels for cooking, to minimise further adverse health effects. By focusing on urban areas, our findings have important public health implications globally because many low-income and middle-income countries are undergoing rapid economic development and experiencing an unprecedented pace of urbanisation, which provides an enormous opportunity to accelerate access to clean energy.30

Our study provides a unique finding that, even among users of clean fuels, use of ventilation was associated significantly with reduced risks of all-cause and cardiovascular mortality. In both our previous study in rural China26 and the PURE study,29 use of ventilation was associated with lower mortality risks among users of solid fuels. Our current study has, therefore, extended evidence for the health benefit of ventilation by showing that use of ventilation was associated with a lower risk of all-cause and cardiovascular mortality, even among those using clean fuels for cooking.

Our study has several limitations. First, classification of cooking fuel use might be inaccurate, because fuel use information was gathered by self-report; moreover, the three most recent residences might not cover early-life exposure. However, our resurvey of cooking fuel use showed reasonable reproducibility (weighted \( k \) value of 0·56). Furthermore, we expect that not knowing about cooking fuel type during early life should not have a major effect on our results because the massive transition of cooking fuel types in China only started from the 1990s. Moreover, misclassification of fuel use would probably lead to underestimation rather than overestimation of the association between solid fuel use and mortality risk, because of the dilution effect of random measurement errors in the exposure.31 Second, although we have carefully adjusted for several covariates related to socioeconomic status (ie, educational level, household income, and occupation), residual confounding by unmeasured socioeconomic factors remains possible. Third, residual confounding might be present from concurrent exposure to ambient air pollution, to which household solid fuel use was a contributing source.4 Nevertheless, although we did not have data to adjust for ambient air quality, we stratified all analyses by study area, which was expected to at least partly account for ambient air pollution exposure, assuming a similar exposure level to participants from the same area. Finally, we only recorded the primary fuel used for cooking as the exposure, and we did not obtain data for secondary types of fuel use, types of cooking stoves, and effectiveness of ventilation facilities, all of which might affect the exposure level to solid fuel use. We expect to supplement this information in future surveys and implement direct measurement of personal exposure to household air pollution to improve the exposure assessment.

In conclusion, our findings underscore the urgency of improving access to both clean fuels and ventilation facilities, which is especially promising for public health gains in low-income and middle-income countries, where an unprecedented pace of urbanisation is ongoing.

Contributors
KY, ZC, LII, and TW had the idea for the study and contributed to study design. YC, ZB, LII, and YC coordinated data acquisition and standardisation. KY and GQ analysed data. JLI, GQ, CW, AP, Liang, FBH, and TW interpreted data. KY wrote the draft report, and all authors contributed to revision of the report. JLI, CT, YG, ZB, LY, ZC, and LII provided administrative, technical, or material support. ZC and LII are members of the China Kadoorie Biobank Study steering committee and designed and supervised overall study implementation and obtained funding.

Declaration of interests
We declare no competing interests.

Data sharing
Requests for data should be submitted to the China Kadoorie Biobank (CKB) Data Access Committee. As stated in the CKB data policy, the CKB Study Group (as data custodian) must maintain the integrity of the database for future use and regulate data access to comply with previous 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.

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For CKB data see https://www.ckbiobank.org/site/Data+Access/
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