LETTER

Household polluting cooking fuels accelerate biological aging among middle-aged and older adults: A two-wave panel study

Haisheng Wu,[1] Jiazhen Zheng,[2] Hongli Wan,[3,4] Dongdong Zhang,[5,6,*] and Chengfu Cai[5,6,*]

[1]School of Public Health, LKS Faculty of Medicine, The University of Hong Kong, Hong Kong SAR 999077, China

[2]Bioscience and Biomedical Engineering Thrust, Systems Hub, The Hong Kong University of Science and Technology (Guangzhou), Guangzhou 511453, China

[3]Department of central laboratory, Xi'an No.1 Hospital, The First Affiliated Hospital of Northwest University, Xi'an 710002, China

[4]Xi'an Key Laboratory for Innovation and Translation of Neuroimmunological Diseases, Xi'an No.1 Hospital, Xi'an 710002, China

[5]School of Medicine, Xiamen University, Xiamen 361102, China

[6]College of Otorhinolaryngology Head and Neck Surgy, Xiamen Haicang Hospital, Xiamen 361026, China

*Correspondence: 18150365465@163.com (D.Z.); caicf@xmu.edu.cn (C.C.)

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Dear Editor,

Aging is regarded as the "common soil" of age-related chronic diseases and mortality,[1] which is characterized by the progressive decline in the physiological functions of living organisms.[2] Aging-related diseases have been estimated to account for 51.3% of the global disease burden.[3] Although definitive methods for halting the biological aging process have not been developed yet, the process of biological aging may potentially be delayed or even reversed through enhancements in lifestyle, mental status, socioeconomic, and environmental conditions.

Polluting solid fuels (coal, wood, biomass) constitute a significant portion of domestic cooking resources globally, leading to serious household air pollution through incomplete combustion.[4] This issue remains a critical concern in middle- and low-income countries,[5] notably in nations like China, which also faces the additional challenge of an aging population. Despite these concerns, the effects of household polluting fuel use on biological aging acceleration have not been deeply explored, this study aims to investigate these effects and fill the existing research gap in understanding how such household fuel use may contribute to the acceleration of biological aging.

DATA SOURCE OF THIS STUDY

In this study, data from the China Health and Retirement Longitudinal Study (CHARLS) were collected for 5,576 participants aged 45-80 years, including information on blood biomarkers, physical measurements, and cooking fuel use in both the 2011 baseline survey and the 2015 follow-up survey (Figure 1A). All participants in the CHARLS program provided written informed consent. The protocol and procedures of CHARLS follow the ethical guidelines outlined in the Declaration of Helsinki and have been approved by the Ethics Review Committee of Peking University (IRB00001052-11015).

ASSESSMENT OF HOUSEHOLD COOKING FUEL USAGE

Cooking fuels consisting of wood, coal, or crop residues were classified as polluting solid fuels, while those consisting of natural gas, liquefied petroleum gas, biogas, electricity, or solar energy were categorized as cleaner fuels. Participants were divided into the four following categories based on changes in their cooking fuel use during the baseline and follow-up surveys: consistent cleaner, cleaner to solid, consistent solid, and solid to cleaner.

ASSESSMENT OF BIOLOGICAL AGING

In this study, we constructed synthetical indices of biological age using multiple clinical biomarkers of blood biochemical markers and physical measurements, based on the Klemera–Doubal method (KDM) that has been validated in Chinese middle-aged and older adults.[1,6] The KDM biological age (KDM-BA) is derived from information from *m* regression lines that regress chronological age on selected *m* biomarkers in a specific population. The formula is as follows:

$$BA = \frac{\sum_{i=1}^{m}(x_i - q_i)\frac{k_i}{s_i^2} + \frac{CA}{s_{BA}^2}}{\sum_{i=1}^{m}\left(\frac{k_i}{s_i^2}\right)^2 + \frac{1}{s_{BA}^2}}$$

where BA and CA represent the KDM-BA and chronological age of an individual, respectively. The x_i is the measured value of the biomarker *i*, and k_i, q_i and s_i represent the slope, intercept and root mean squared error obtained from the regression of the biomarker *i* on CA, respectively. The value s_{BA}^2 is the estimated variance in CA explained by the selected biomarker set.

Ideally, a synthetical KDM-BA should capture the aging processes in a range of biological systems. The selection of biomarkers was based on their function in the aging process, their application in previous studies, and their availability in the CHARLS. A total of 11 biomarkers were selected for constructing KDM-BA: white blood cell count, platelets count, high-sensitivity C-reactive protein, peak expiratory flow, triglycerides, total cholesterol, glycated hemoglobin, creatinine, blood urea nitrogen, mean corpuscular volume, and systolic blood pressure. These biomarkers reflect inflammatory, immune, metabolic, cardiovascular, lung, liver, kidney, and hematologic functioning.

Using the "BioAge" R package version 0.1.0, the KDM algorithm was constructed separately by sex. The non-normally distributed triglycerides and high-sensitivity C-reactive protein were logarithmically transformed prior to fitting the KDM algorithm. Given that all study participants survived from the 2011 baseline to the 2015 follow-up, and considering that the effectiveness of biological age indicators is typically assessed by their ability to predict future mortality risk,[6] we initially trained the KDM model using data from the 2015 survey (training samples) and obtained the predicted KDM-BA. Subsequently, the fitted KDM model was applied to the 2011 baseline data (test samples) to estimate the corresponding KDM-BA. Finally, the KDM-BA acceleration (KDM-BAA), defined as the residue between KDM-BA and chronological age, was further computed to capture the variations in the biological aging process among participants. A positive KDM-BAA indicates that an individual is biologically older in terms of physiological function.

VALIDATION OF BIOLOGICAL AGING

The validation analyses for KDM-BA and KDM-BAA included three parts: 1) examining the Pearson correlation coefficient between KDM-BA and chronological age for both training samples (2015 follow-up data) and test samples (2011 baseline data); 2) evaluating the numerical distribution of KDM-BAA; 3) investigating the association of KDM-BAA at the 2011 baseline and 2015 survey with the risk of all-cause mortality between 2015 and 2020 using hazard ratio (HR) from Cox proportional hazard models. Referring to the previous study,[6] the Cox model was adjusted for age, sex, body mass index (BMI), education, marital status, residence, alcohol consumption, and smoking history.

The results indicated that the constructed KDM model performed well in fitting and predicting chronological age; the Pearson correlation coefficients between KDM-BA and chronological age were 0.96 at both baseline and follow-up (Figure 1B). The estimated KDM-BAA was primarily distributed within a range of -5 to 5 years (Figure 1C). Additionally, per one-year increase in KDM-BAA at baseline and at follow-up was associated with an 11% (HR = 1.11, 95% CI: 1.05, 1.16) and 14% (HR = 1.14, 95% CI: 1.08, 1.20) increased subsequent mortality risk, respectively (Figure 1D).

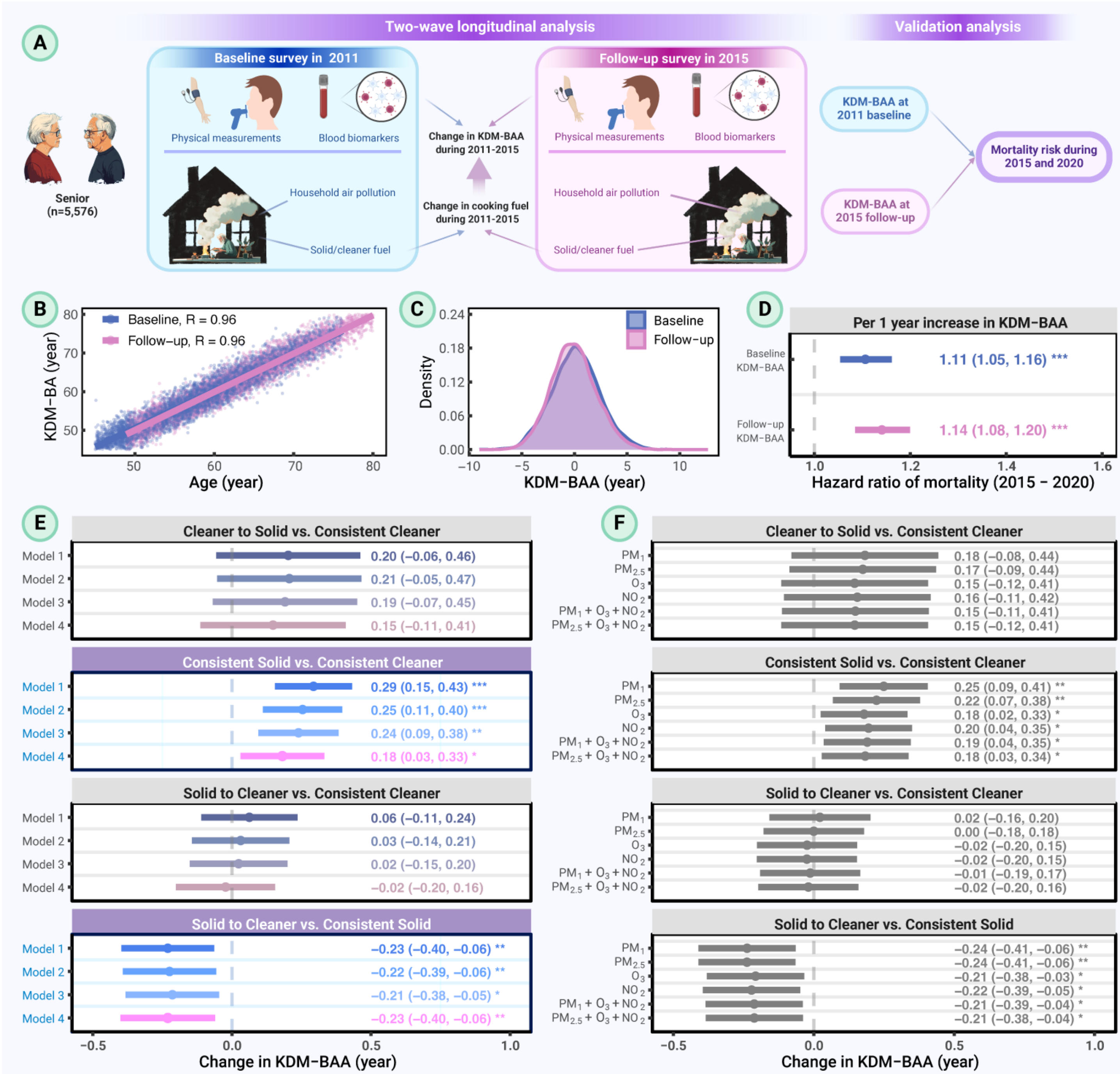

Figure 1. Unraveling aging response to household polluting cooking fuels (A) The workflow of this study. (B) Scatterplots and fitted lines between KDM-BA and chronological age. The value of *R* represents Pearson correlation coefficient. (C) Numerical distribution of KDM-BAA. (D) Association of KDM-BAA with 2015-2020 all-cause mortality. (E) Estimated changes in KDM-BAA associated with changes in cooking fuel usage. Model 1 was the crude model; Model 2 was adjusted for age, sex, education, marital status, and BMI; Model 3 was adjusted for covariates in Model 2 and for alcohol consumption, smoking history, social activity engagement, and depressive symptoms; Model 4 was adjusted for covariates in Model 3 and for residence, and personal earnings after tax. (F) Estimated changes in KDM-BAA associated with changes in cooking fuel usage in sensitivity analyses, by additionally adjusting outdoor pollutant exposure concentrations in Model 4. Symbols *, **, and *** represent $P < 0.05$, $0.001 \le P < 0.01$, and $P < 0.001$, respectively.

STATISTICAL ANALYSIS

A change-to-change analysis with multiple linear models was performed to investigate the association between the change in household cooking fuel usage and the concurrent change in KDM-BAA during the study period. The change-to-change analysis is fundamentally a self-controlled method that relies solely on within-individual data, which has been demonstrated to yield valid results comparable to those from randomized controlled trials by minimizing the impact of unobserved, time-invariant confounding factors. A set of sequential adjustment models with various levels of adjustments was performed to explore the robustness of effect estimates: Model 1 was the crude model without any adjustment; Model 2 was adjusted for age, sex, education, marital status, and BMI; Model 3 was adjusted for the same covariates as in Model 2 and for alcohol consumption, smoking history, social activity engagement, and depressive symptoms measured by the 10-item Center for Epidemiological Studies-Depression Scale; Model 4 (the fully adjusted model) was adjusted for the same covariates as in Model 3 and for residence, and personal earnings after tax. Based on Model 4, sensitivity analyses were performed to assess the influence of outdoor air pollution on effect estimations by additionally and sequentially adjusting for four pollutants [particulate matter with an aerodynamic diameter of ≤ 1 μm (PM_1) or ≤ 2.5 μm ($PM_{2.5}$), ozone (O_3), and nitrogen dioxide (NO_2)] and their combination. All analyses were performed using R (version 4.3.1; R development Core

Team).

UNRAVELING AGING RESPONSE TO HOUSEHOLD POLLUTING COOKING FUELS

The age (± SD) of the 5,576 participants (2,571 males and 3,005 females) was 58.3 ± 7.8 years. During the four-year follow-up, 1,032 (18.5%) participants transitioned from using solid to cleaner cooking fuels, while 1,847 (33.1%) and 2,344 (42.0%) maintained consistent usage of cleaner and solid cooking fuels, respectively. All models with different adjustment levels show consistent results (Figure 1E). In the fully adjusted model (Model 4), consistent solid fuel users showed an acceleration of 0.18 (95% CI: 0.03, 0.33) years in KDM-BAA compared with consistent cleaner fuel users; participants who transitioned from solid to cleaner fuels exhibited a decline of 0.23 (95% CI: 0.06, 0.40) years in KDM-BAA compared with those with consistent solid fuel status. The sensitivity analyses with additional adjustments for PM_1, $PM_{2.5}$, NO_2, or O_3 did not alter findings from the Model 4, as depicted in Figure 1F.

To the best of our knowledge, this is the first study with a panel study design unraveling the association between the usage of household polluting cooking fuel and biological age acceleration in middle-aged and older people. There may have been errors in reporting cooking fuel use by participants in a large-scale survey, but such exposure misclassifications are likely to be non-differential. Although potential residual confounding was inevitable, the consistency across a series of sequence-adjusted models and sensitivity analyses supports the robustness of the results. Our findings align with the recent study revealing the harmful effects of household air pollution from solid fuel combustion on epigenetic aging.[4] Furthermore, the adverse health impacts of solid fuel use, as documented in previous research, further corroborate our results.[7,8] Further studies are warranted to provide causal evidence and to explore the broader application of our findings in policy-making and public health interventions.

Potential physio-pathological mechanisms of polluting fuels on biological aging have been explored. The incomplete combustion of polluting cooking fuels leads to high-level harmful pollutants in the house, such as heavy metals, volatile organic compounds, and black carbon.[7] Exposure to these household harmful pollutants may induce excessive inflammation and oxidative stress,[7] effectively triggering immunosenescence[8] and epigenetic aging,[4] followed by an acceleration of aging-related functional deterioration.[9]

INEQUALITY IN ACCESS TO CLEANER FUELS FOR HOUSEHOLD COOKING

Household air pollution owing to fuel use is a particularly pressing issue. In 2022, 12.2% Chinese population (174.69 million people) primarily relied on polluting fuels and technologies for cooking, with the percentage nearly doubling to 24.2% in rural areas (126.67 million people).[10] According to the latest survey data from CHARLS in 2020, the proportion of middle-aged and elderly people in China who use polluting solid fuel as their major cooking fuel was still as high as 26.0%. Globally, about 2.3 billion people (around a third of the global population) rely on polluting fuels such as kerosene, biomass and coal for cooking, most of whom are poor and live in rural areas of low- and middle-income countries.[5] It's essential to expand access to cleaner fuels and develop technologies to reduce the inequality of access to cleaner cooking fuels worldwide, especially in rural areas with a high proportion of older population.

PERSPECTIVE

In conclusion, this large-scale panel study identified the association between polluting cooking fuel use and the acceleration of biological aging, and that transitioning from solid to cleaner cooking fuel use may contribute to the attenuation of biological aging in middle-aged and older adults. The benefits of transitioning to cleaner energy extend far beyond convenience, with significant implications for promoting healthy aging. Combined with prior experience from high-income countries, which demonstrates that aggressive air quality management of household combustion of polluted fuels can significantly increase life expectancy over short timeframes, the significant findings of this study provide crucial insights into the benefits of transitioning from polluting to cleaner cooking fuels and suggest potential strategies for promoting healthy aging.

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AUTHOR CONTRIBUTIONS

H.S.W. and D.D.Z. designed research; H.S.W. and D.D.Z. performed research; H.S.W. and J.Z.Z. analyzed data; H.S.W. and D.D.Z. wrote the paper; C.F.C. provided methodological guidance; H.S.W., H.L.W. and C.F.C. edited the paper.

DECLARATION OF INTERESTS

The authors declare no competing interests.

ETHICAL STATEMENT AND PATIENT CONSENT

The human subjects research was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Peking University (IRB00001052-11015). All study participants in the CHARLS provided written informed consents.

DATA AND CODE AVAILABILITY

Data on participants were provided by the CHARLS (https://charls.pku.edu.cn/en/). Ambient pollutant concentration data were collected from the ChinaHighAirPollutant (CHAP) dataset (https://weijing-rs.github.io/product.html).