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Research Article

Pain in Solid and Clean Fuel Using Households

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Household air pollution from solid cooking fuel use influences multiple health outcomes, but its association with body pain remains poorly understood. This was a longitudinal study of 8880 adults who participated in the China Health and Retirement Longitudinal Study (CHARLS) from 2011 to 2018. Household cooking fuels were extracted from the baseline household questionnaire. Transitions in cooking fuels from 2011 to 2018 were also identified. Body pain status was reported in the three waves of surveys conducted in 2011, 2015, and 2018. The associations between cooking fuel type, fuel transition, and pain site number were examined using generalized estimating equations. Among the 8880 participants, 41.4% ($n = 3680$) primarily used clean fuels for cooking, and 58.6% ($n = 5200$) used solid ones at baseline. Cooking with solid fuels was associated with more pain sites (incidence rate ratio (IRR): 1.14; 95% confidence interval (CI): 1.08 to 1.21), but a slower rate of pain sites increases from 2011 to 2018 (IRR = 0.78; 95% CI: 0.71 to 0.86, for 2018 × solid fuels). Compared with those who persistently used clean fuels for cooking, the number of pain sites increased by 10% in participants who transiting from using solid to clean fuels (IRR = 1.10; 95% CI: 1.04 to 1.18), by 21% in those transiting from cooking with clean to solid fuels (IRR = 1.21: 95% CI: 1.08 to 1.35) and by 25% among those persistent using solid fuels for cooking (IRR = 1.25; 95% CI: 1.18 to 1.34). Our findings provided new evidence linking using solid fuels for cooking with more pain sites, but a slower rate of pain sites increases. Public health efforts should focus on fuel transition and take measures to help clean fuels spread.

1. Introduction

After adopting the United Nations Declaration on the Human Environment in 1972, air quality improvement has become a general trend. However, public health awareness of indoor air pollution has lagged behind outdoor air pollution. Billions of the world's population are still exposed to cooking with solid fuels, a major source of indoor air pollution [1]. Compared with those using cleaner fuels (like gas or electricity), burning of solid fuels (such as coal, wood, or crop residues) in inefficiency simple stoves generates substantial air pollutants, including carbon monoxide, nitrogen dioxide, and particulate matter, and results in adverse consequences for air qualities [2], climate change [3], and human health [4, 5].

In 2019, household air pollution was ranked 9th in terms of attributable deaths among 69 risk factors considered potentially modifiable [6]. About 2.3 million deaths and 91.5 million disability-adjusted life years, most occurring in China and India, were due to household air pollution from polluting cooking fuel [7]. Epidemiological studies have linked cooking with solid fuels to a broad range of health problems, including respiratory illness [8], cardiovascular diseases [9, 10], arthritis [11], cognitive decline [12], and depression [13]. Existing studies showed that outdoor air pollution was associated with body pain, including headaches [14], chest [15], and angina pectoris [16], but little is known about the relationship between indoor air pollution and body pain.

Pain is defined by the International Association for the Study of Pain (IASP) as an unpleasant sensory and emotional experience associated with actual or potential tissue damage [17]. It is known that pain is associated with consequences that far exceed itself, including adverse biological (i.e., cognitive decline and disability) [18, 19], psychological (i.e., depression, anxiety, and stress) [20], and social conditions (i.e., economic costs, isolation, and social withdrawal) [21, 22]. According to the Global Burden of Disease Study 2019 [23], pain conditions such as low back pain, neck pain, and headache were the most important cause of years lived with disability. Indeed, the pain increases with age and is the main reason people seek healthcare services [24]. However, it is often neglected or shifted attention to diagnosed diseases after treatment. In this setting, additional attention to the pain is warranted.

2. Mechanisms, Materials, and Methods

2.1. Theoretical Mechanism. The classification of pain is various and depends on the perspectives. When considering the duration of pain, the cutoff of three months is used for defining acute and chronic pain. According to the cause of pain, the latter can be further divided into the following seven categories: chronic primary pain, chronic neuropathic pain, chronic secondary visceral pain, chronic posttraumatic and postsurgical pain, chronic secondary headache and orofacial pain, chronic cancer-related pain, and chronic secondary musculoskeletal pain [25]. In addition, pain can be classified into different types based on its location, such as headache, chest pain, and low back pain. As the site of pain is easily felt, screened, and located, many epidemiological studies used body parts to define the pain [26–28]. The current study focused on the association between solid fuel usage and the number of pain sites.

2.1.1. Air Pollution and Musculoskeletal Pain. Musculoskeletal pain is generally defined as pain caused by joints, bones, muscles, and tendons. According to the Standardized Nordic Questionnaire [29], the affected body area(s) of musculoskeletal pain include neck, shoulder, upper back, elbows, lower back, wrists/hands, hips/thighs, knees, and ankles/feet. Previous studies have found that exposure to air pollution was associated with musculoskeletal pain [27], bone fractures [30], and osteoporosis [31]. Indeed, air pollution containing particulate matter leads to systemic inflammation [32], which is directly associated with immune cells and nociceptors and indirectly modulates pain intensity [26, 33]. In addition, the plausibility of an association between air pollution and musculoskeletal pain is supported by studies showing musculoskeletal pain associated with tobacco smoking [34, 35]. Carbon monoxide is not only a component of smoke but also an important component of ambient and household air pollution. It leads to reduced perfusion and malnutrition of tissues and causes these tissues to respond inefficiently to mechanical stress, which may impair the bone remodeling process [34].

2.1.2. Air Pollution and Pain in Other Parts of the Body. Evidence exists on the association between air pollution and headache and chest pain. In a randomized stove intervention trial [36], the headache was substantially reduced in the plancha group relative to the group using open fires for the follow-up period. A recent review [37] also has found that exposure to airborne pollutants, especially particulate matter and nitrates, is associated with headaches. As we breathe, the pollutants produced by traffic, industrial processes, and burning fossil fuels may enter the bloodstream via the lungs or move directly to the brain via the olfactory nerves. Reactive pollutant chemicals are then activated in the body and provoke inflammatory processes that may cause headaches or migraines [14, 38, 39]. Chest pain, where angina commonly occurs, is also related to air pollution [16, 40]. The pollutants may cause chest pain by affecting the cardiovascular system through systemic inflammation, systemic oxidative stress, thrombosis, and coagulation [41, 42]. Although, few studies [43] have found a relationship between air pollution and abdominal pain. As air pollutants can enter the body via the lungs and gut, growing evidence links its exposure to gastrointestinal and respiratory impairments and diseases [44]. The directly toxic effects starting from the lungs may influence the gastrointestinal system through the gut-lung axis, leading to gut microbiota effects [45], gut permeability effects, and even systemic inflammation.

2.1.3. The Development of Multisite Pain. Pain rarely occurs in a single anatomical location, and the more widespread the pain is, the higher the impact on functioning and health [46, 47]. The study of multisite pain and its underlying factors has gained scientific interest internationally. One possible mechanism for explaining the development of multisite pain is repeated stressors. Individual risk factors may act accumulatively through the concept of allostatic load, whereby repeated stressors increase the physiological stress response in individuals and further lead to widespread pain [48]. Another potential mechanism for explaining why pain becomes widespread is central sensitization [49], which is an increased synaptic response in nociceptive neurons in the central nervous system.

Based on the discussion above, ambient air pollution and smoking are important risk factors for pain localized in different regions, including the musculoskeletal system, chest, head, and abdomen. Few studies are exploring household air pollution and the trajectory of pain sites. Still, ambient air pollutants and tobacco smoking have a similar component with household air pollutants, like carbon monoxide and particulate matter, and this provided us with a theoretical basis for studying the relationship between household air pollution and pain. In addition, as the exposure may persist, single pain may develop into multisite pain. This study seeks to answer the following research questions:

(1) Is exposure to solid fuels for cooking associated with more pain sites?

(2) Does transition in solid fuels influence the trajectory of pain sites?

(3) Is exposure to solid fuels for cooking associated with a specific pain site?

2.2. Study Design and Population. The China Health and Retirement Longitudinal Study (CHARLS) is an open-access dataset that enrolled a nationally representative sample of Chinese residents aged 45 and above [50]. Briefly, CHARLS enables the study of the older population's health in China patterned after the US Health and Retirement Study (HRS) and related aging surveys worldwide. This national survey has collected rich information on the respondents' social, economic, behavioral, and health. The first survey was conducted in 2011 with a response rate of 80.5%, and 17708 individuals were interviewed. Then, these participants are followed up once every two years, and data from the repeated surveys performed in 2011, 2013, 2015, and 2018 are available. The details of the design and methods of CHARLS have been described extensively. CHARLS has been approved by the Biomedical Ethics Review Committee of Peking University.

For the current study, we used data from three repeated surveys of the CHARLS (2011, 2015, and 2018) because information on body pain differed in the second survey (2013) and then limited participants to 45-75 years old at baseline. After excluding those missing data on cooking fuel in 2011 or 2018, without data on body pain across three repeated surveys, and missing baseline data on any other variables of interest, the final analytic sample included 8880 participants, as detailed in Figure 1.

2.3. Outcome Ascertainment. Body pain was defined using one item: are you often troubled with any body pains? If the answer was "yes," then the next question would be asked: on what part of your body do you feel pain? Please list all body parts that are currently in pain (including head, shoulder, arm, wrist, fingers, chest, stomach, back, waist, buttocks, leg, knees, ankle, toes, and neck). The primary outcome of the study was the number of body pain sites.

Specific body pain site was the second outcome in this study. According to previous studies [51, 52], we categorized the above 15 pain sites into 7 regions: head, neck/shoulders, arms/hands, frontal torso/genitals, back, buttocks, and legs/feet.

2.4. Exposure Measurement. Household cooking fuels were extracted from the baseline household questionnaire, which asked, *what is the main source of cooking fuel?* The categories of this question include (1) solar, (2) coal, (3) natural gas, (4) liquefied petroleum gas, (5) electric, and (6) crop residue/wood burning. According to previous studies [53, 54], respondents in households that answered coal, crop residue, or wood burning were deemed primarily to use solid fuels for cooking. In contrast, those who used natural gas, marsh gas, liquefied petroleum gas, or electricity were considered to use clean fuels.

Transition in fuel use was proxied using data from 2011 to 2018, and we identified change in fuel use into four categories: (1) solid fuels in 2011/solid fuels in 2018; (2) solid fuels in 2011/clean fuels in 2018; (3) clean fuels in 2011/solid fuels in 2018; (4) clean fuels in 2011/clean fuels in 2018. The first condition was considered to be always using solid fuels, and the last was deemed to be always using clean fuels. Solid to clean fuels presented those who used solid fuels for cooking in 2011 but switched to clean fuels in 2018, whereas those who used clean fuels for cooking in 2011 but switched to solid fuels in 2018 were deemed clean to solid fuels.

2.5. Covariates. Based on previous studies [12, 53, 54], age, gender, education level, marital status, residence, currently working, smoking status, alcohol consumption, number of diseases, household consumption expenditure, number of people living in the household, and heating fuel types were chosen as covariates and acquired from the baseline questionnaire (survey in 2011). The categories of most covariates were according to the questionnaire, including gender (male or female), education level (less than lower secondary, upper secondary, and vocational training or tertiary), residence (rural village or urban community), currently working (yes or no), smoking status (never or current/ever), and alcohol consumption (never or current/ever). Currently working indicates the respondent engaged in any work in the past year. Smoking status indicates whether the respondent reports ever smoking, and alcohol consumption indicates whether the respondent has had any alcoholic beverages in the past. We reclassified five variables: marital status, number of diseases, household consumption expenditure, number of people living in the household, and heating fuel types. In the database, the categories of marital status include (1) married with spouse present, (2) married but not living with spouse temporarily for reasons such as work, (3) separated, (4) divorced, (5) widowed, or (6) never married. Marital status in the study was classified as married and unmarried. Married included the first two statuses, whereas unmarried included the last four statuses. Given that multimorbidity (having at least two diseases at the same time) is associated with a higher risk of mortality and adverse health outcomes [55], we categorized the number of conditions (coded as 0, 1, >1) in our analyses. Household consumption expenditure indicates the amount of total household consumption as aggregated from all consumption activities, including food and other activities, and is calculated as annual expenditures. We used household consumption expenditure to represent the economic level of the household, which was confirmed as a better measure than income in developing countries. According to other studies [5, 56], we classified it as a four-categorical variable by quartiles (first quartile, < CNY¥9201; second quartile, ¥9201 to <16700; third quartile, ¥16700 to <27760; fourth quartile, ≥ ¥27760). The number of people living in the household is the number of people coresiding with the respondent, including the respondent. Generally, the family structure of two persons is composed of the respondent and the spouse. In contrast, more than two people's family structure includes the respondent, the spouse, and their children. Thus, the number of people living in the household was classified as one person, two people, or more than two people in the analyses. Similar to the categories of cooking fuels, we reclassified heating fuels as clean fuels, solid fuels, and other fuels.

2.6. Statistical Analysis. The baseline characteristics of the study sample are presented as mean (standard deviation (SD)) for continuous variables, mean (interquartile range (IQR)) for count data, and number (percentage) for categorical variables, respectively. We compared baseline characteristics of the study sample according to the type of cooking fuels using Pearson's chi-square tests, analysis of variance (ANOVA), and Kruskal-Wallis rank-sum tests. In the primary analyses, the association between baseline polluting cooking fuels and the number of pain sites from 2011 to 2018 was analyzed using a repeated-measure negative

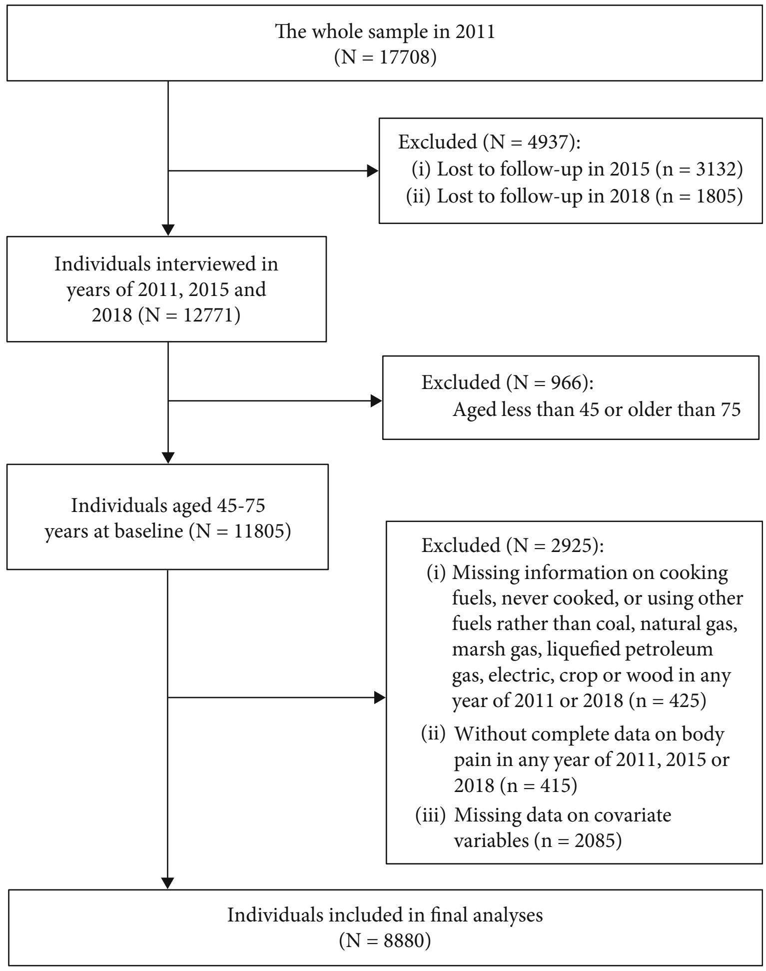

Figure 1: Sample selection steps.

binomial regression analysis by the generalized estimating equation (GEE) method with an unstructured correlation structure after the model selection (Table S1 & S2) [57, 58]. The results are presented as the incidence rate ratios (IRRs) with 95% confidence intervals (CIs). Three models adjusted for factors that might affect the association, including age, gender, marital, residence, education level, and currently working (model 1); further adding smoking status, alcohol consumption, the number of pain sites at baseline, and the number of diseases (model 2); and adding household consumption expenditure, the number of people living in the household, and heating fuels (model 3). We further included statistical interaction terms between survey year and cooking fuel type to investigate whether fuel type was related to the rate of change in pain site number over time. The association between cooking fuel's transition (2011/2018) and the number of pain sites was also analyzed using a GEE model with a log link and negative binomial distribution and tested with the same covariates as our primary analyses.

A series of exploratory and sensitive analyses were performed to assess the robustness of the primary findings. First, we evaluated the influence of moderators on the association between fuel types and the number of pain sites by assessing interaction terms of fuel types and each covariate. Second, considering diverse effects on pain sites, we examined the associations between polluting cooking fuels and each pain site (separate models) by using a GEE model with a logit link and logistic distribution. Results are presented as odds ratio (OR) with 95% CI. Third, we compared the baseline characteristics of those excluded for missing and included data. We further performed multiple imputations by chained equations (MICE) and repeated the modeling analyses using the imputed datasets to address potential bias from missing data [59]. Fourth, we excluded those having chronic diseases at baseline and repeated the analyses. Fifth, we further controlled for physical activity in the model. Finally, we examined the associations of cooking fuel types and the number of pain sites using different working correlation structures to address potential bias from other working correlation structures. The detailed analyses are provided in Supplementary Methods.

Analyses were performed with Stata/SE 17.0, and a two-side P value level of 0.05 was considered the threshold for statistical significance.

3. Results

3.1. Baseline Sample Characteristics. Of the 8880 eligible participants, 47.9% were male, and the mean baseline age was 57.1. Among these, 41.4% ($n = 3680$) primarily used clean fuel for cooking, and 58.6% ($n = 5200$) used solid fuels for cooking (Table 1). Participants who cooked with solid fuels were more likely to have lower levels of education, live in rural villages, have no employment, be in a lower quartile level of household consumption expenditure, use solid heating fuels, and have more diseases when compared to those using clean cooking fuels. Table S3 provides additional information about the distribution of cooking fuel types and fuel transitions from 2011 to 2018. In brief, from 2011 to 2018, 3324 (37.4%) participants persistently used clean fuels for cooking, 2829 (31.9%) participants kept using solid fuels for cooking, 2371 (26.7%) individuals transitioned from using solid to clean fuels, and 356 (4.0%) individuals transitioned from cooking with clean to solid fuels.

3.2. Association of Cooking with Solid Fuels and the Number of Pain Sites. Table 2 presents the association between cooking with solid fuels and the number of body pain sites. In model 1, individuals who used solid fuels for cooking experienced more pain sites than those who used clean fuels (IRR = 1.47; 95% CI: 1.39 to 1.56). When smoking status, alcohol consumption, the number of diseases, and the number of pain sites at baseline were added in model 2 and household consumption expenditure, the number of people living in the household and heating fuels were added in model 3, the parameter estimate for polluting cooking fuels weakened but was still related with the increased number of pain sites (model 2: IRR = 1.19, 95% CI: 1.13 to 1.25; model 3: IRR = 1.14, 95% CI: 1.08 to 1.21).

When considering transitions in cooking fuel, in model 1, the number of pain sites increased in participants who were transiting from using solid to clean fuels (IRR = 1.36; 95% CI: 1.27 to 1.47), transiting from cooking with clean to solid fuels (IRR = 1.39; 95% CI: 1.21 to 1.59), and those persistent using solid fuels for cooking (IRR = 1.71; 95% CI: 1.60 to 1.84) compared with those who persistently used clean fuels for cooking. Adjustment for more covariates in model 2 and model 3 resulted in weaker parameter estimates.

3.3. Association of Cooking with Solid Fuels and Short-Term Trajectories of Body Pain Sites. Results from the interaction terms suggest that the effect of using solid cooking fuels was modified by time (Table 3 and Figure 2). In model 1, individuals who used solid cooking fuels had a slower rate of pain site increase (IRR = 0.88; 95% CI: 0.80 to 0.98, for 2015 × solid fuels; IRR = 0.70; 95% CI: 0.64 to 0.77, for 2018 × solid fuels). In the fully adjusted model, the interaction effect was attenuated in 2015 (IRR = 1.02; 95% CI: 0.90 to 1.14, for 2015 × solid fuels) but remained statistically significant in 2018 (IRR = 0.78; 95% CI: 0.71 to 0.86, for 2018 × solid fuels).

Similarly, a negative interaction was observed between cooking fuel transition and time on the body pain sites in the fully adjusted model (IRR = 0.78; 95% CI: 0.69 to 0.87, for 2018 × solid to clean; IRR = 0.76; 95% CI: 0.68 to 0.85, for 2018 × always solid); and the slower rate of body pain site increase was observed in those who persistently used solid fuels for cooking as well as those transited from cooking with solid to clean fuels compared with those persistently used clean fuels (Table 3 and Figure 3).

3.4. Subgroup Analyses and Sensitivity Analyses. In the subgroup analyses, statistically significant interactions (P for interaction <0.05) on the number of pain sites were detected for fuel types across subgroups of gender, currently working, smoking status, number of diseases, and household consumption expenditure, as detailed in Table S4. The effect of using solid cooking fuels on the number of pain sites was more pronounced among males, smokers, those not having jobs, those with the highest level of household consumption expenditure, or those with one chronic disease (Figure S1).

The sensitivity analyses yielded similar findings to our primary analyses (Tables 2 and 3). First, we assessed the impact of cooking with solid fuels on the specific pain, and additional information is presented in Table S5 and Figure S2. Compared to clean fuel use for cooking, using solid fuels was associated with higher odds of leg/feet pain (OR = 1.19, 95% CI: 1.10 to 1.28), buttock pain (OR = 1.22, 95% CI: 1.07 to 1.39), back pain (OR = 1.16, 95% CI: 1.05 to 1.28), frontal torso/genital pain (OR = 1.12, 95% CI: 1.04 to 1.21), arm/hand pain (OR = 1.28, 95% CI: 1.17 to 1.39), neck/shoulder pain (OR = 1.12, 95% CI: 1.03 to 1.21), and headache (OR = 1.15, 95% CI: 1.05 to 1.25). Second, the baseline characteristics varied between the excluded and included participants (Table S6). We performed multiple imputations by chained equations (MICE) to address potential bias from missing data and repeated the modeling analyses using the imputed datasets. The associations were not materially altered (Table S7 & S8). Third, we excluded those with chronic diseases at baseline to reduce bias caused by diseases. The results were similar to those observed in our primary analysis (Table S9). Still, the interaction terms between exposure variables and time were not statistically significant (Table S10), suggesting the effect of chronic diseases on the rate at which the number of pains increased. Fourth, gathering and using solid fuels increase the risk of musculoskeletal injuries, which also cause body pain; thus, we further controlled for physical activity, and there were no changes in the statistical significance of associations (Table S11 & S12). Finally, to address potential bias from different working correlation structures, we repeated the modeling analyses using the other two types of working correlation structures, and the main results remained robust (Table S13).

4. Discussion

Our main findings were that cooking with solid fuels in this Chinese population-based study was associated with more pain sites, but a slower rate of pain sites increases. In addition, males, smokers, those not having jobs, those with the highest household consumption expenditure, and those with one chronic disease responded more strongly to the harmful

Table 1: Baseline characteristics of study participants by cooking fuel types in 2011.

Variables	Clean fuels $n = 3680$	Solid fuels $n = 5200$	Total $N = 8880$	P value
Number of pain sites, median (IQR)	0 (1)	0 (2)	0 (2)	<0.001[‡]
Age, mean (SD)	56.2 (7.7)	57.7 (7.7)	57.1 (7.7)	0.901[*]
Gender, n (%)				0.595[†]
Male	1774 (48.2%)	2477 (47.6%)	4251 (47.9%)	
Female	1906 (51.8%)	2723 (52.4%)	4629 (52.1%)	
Education level, n (%)				<0.001[†]
Less than lower secondary	3011 (81.8%)	4874 (93.7%)	7885 (88.8%)	
Upper secondary & vocational training	574 (15.6%)	311 (6.0%)	885 (10.0%)	
Tertiary	95 (2.6%)	15 (0.3%)	110 (1.2%)	
Marital status, n (%)				0.536[†]
No	302 (8.2%)	446 (8.6%)	748 (8.4%)	
Yes	3378 (91.8%)	4754 (91.4%)	8132 (91.6%)	
Residence, n (%)				<0.001[†]
Urban community	2001 (54.4%)	990 (19.0%)	2991 (33.7%)	
Rural village	1679 (45.6%)	4210 (81.0%)	5889 (66.3%)	
Currently working, n (%)				<0.001[†]
No	1342 (36.5%)	1279 (24.6%)	2621 (29.5%)	
Yes	2338 (63.5%)	3921 (75.4%)	6259 (70.5%)	
Smoking status, n (%)				0.001[†]
Never	2306 (62.7%)	3072 (59.1%)	5378 (60.6%)	
Ever or current	1374 (37.3%)	2128 (40.9%)	3502 (39.4%)	
Alcohol consumption, n (%)				0.496[†]
Never	2233 (60.7%)	3118 (60.0%)	5351 (60.3%)	
Ever or current	1447 (39.3%)	2082 (40.0%)	3529 (39.7%)	
Number of diseases, n (%)				<0.001[†]
0	1297 (35.2%)	1650 (31.7%)	2947 (33.2%)	
1	1117 (30.4%)	1555 (29.9%)	2672 (30.1%)	
>1	1266 (34.4%)	1995 (38.4%)	3261 (36.7%)	
Household consumption expenditure, n (%)				<0.001[†]
First quartile (lowest)	526 (14.3%)	1694 (32.6%)	2220 (25.0%)	
Second quartile	801 (21.8%)	1422 (27.3%)	2223 (25.0%)	
Third quartile	1008 (27.4%)	1210 (23.3%)	2218 (25.0%)	
Fourth quartile (highest)	1345 (36.5%)	874 (16.8%)	2219 (25.0%)	
Number of people living in the household, n (%)				0.003[†]
1	131 (3.6%)	179 (3.4%)	310 (3.5%)	
2	1056 (28.7%)	1666 (32.0%)	2722 (30.7%)	
>2	2493 (67.7%)	3355 (64.5%)	5848 (65.9%)	
Heating fuels, n (%)				<0.001[†]
Clean fuels	1810 (49.2%)	443 (8.5%)	2253 (25.4%)	
Solid fuels	1279 (34.8%)	3984 (76.6%)	5263 (59.3%)	
Others	591 (16.1%)	773 (14.9%)	1364 (15.4%)	

Abbreviations: IQR: interquartile range; SD: standard deviation. [‡]Kruskal-Wallis rank-sum tests; [*]ANOVA: analysis of variance; [†]Pearson's chi-square test.

effects of indoor air pollution. When fuel switching was further considered, our study observed a nonconventional energy transition from clean to solid fuels and highlighted its impact on pain.

The evidence on the association between air pollution and pain is based chiefly on outdoor air pollution or limited to a specific pain site. A stove intervention study [60] in Peru observed reduced headache in the intervention group, those with new chimney-equipped stoves, than those with mostly open-fire stoves in the control group. Another study in multiple countries showed that higher odds of angina pectoris were observed mainly with household solid fuel use [61].

Table 2: Association of fuel types and fuel transitions with body pain sites from 2011 to 2018.

Variables	Model 1 IRR (95% CI)	Model 2 IRR (95% CI)	Model 3 IRR (95% CI)
Fuel types			
Cooking fuels			
Clean fuels	Reference	Reference	Reference
Solid fuels	1.47 (1.39 to 1.56)***	1.19 (1.13 to 1.25)***	1.14 (1.08 to 1.21)***
Transition types			
Fuel transitions			
Always clean	Reference	Reference	Reference
Solid to clean	1.36 (1.27 to 1.47)***	1.14 (1.08 to 1.21)***	1.10 (1.04 to 1.18)**
Clean to solid	1.39 (1.21 to 1.59)***	1.24 (1.11 to 1.39)***	1.21 (1.08 to 1.35)**
Always solid	1.71 (1.60 to 1.84)***	1.31 (1.23 to 1.39)***	1.25 (1.18 to 1.34)***

*$P < 0.05$, **$P < 0.01$, and ***$P < 0.001$. Abbreviations: IRR; incidence rate ratio; CI; confidence interval. Model 1 adjusted for age (continuous), gender (male or female), marital status (unmarried or married), residence (rural or urban), education level (less than lower secondary, upper secondary, and vocational training or tertiary), and currently working (yes or no). Model 2 additionally adjusted for smoking status (never or current/ever), alcohol consumption (never or current/ever), the number of diseases (0, 1, >1), and the number of pain sites at baseline (continuous). Model 3 further adjusted for household consumption expenditure (in quartiles), number of people living in the household (1, 2, >2), and heating fuels (clean fuels, solid fuels, or other fuels).

Other researchers [27, 30] gave evidence of an association between air pollution and musculoskeletal disorders. By comparison, our study is the first to simultaneously investigate the relationship between using solid fuels and the number of pain sites and specific pain sites. It extends previous knowledge by demonstrating that solid cooking fuel use was associated with more pain sites. In addition, we examined the impact of fuel transition on pain and found that transiting from clean to solid fuels and from solid to clean fuels was associated with more pain sites than those who persist in using clean fuels. This finding suggested that despite later switching to clean fuels, it was impossible to quickly offset the hazard from earlier exposure to polluting fuels, which underscored the importance of clean energy.

The potential biological mechanisms by which cooking with solid fuels influences the type and number of pain sites remain unclear; however, clues can be taken from the impact of outdoor air pollution and tobacco smoking on pain. Ambient air pollutants and tobacco smoking have components similar to household air pollutants, like carbon monoxide and particulate matter, and this provided us with a theoretical basis for studying the relationship between household air pollution and pain. The effect of pollution on health is commonly attributable to substantial amounts of pollutants released during combustion, including respirable particulates, carbon monoxide, nitrogen oxides, benzene, and polyaromatic compounds [62]. Sustained exposure to these air pollutants, especially particulate matter, may lead to elevated concentrations of proinflammatory biomarkers in the systemic circulation [63, 64], sensitize nociceptors, and amplify nociceptive input to the central nervous system [65, 66]. Systemic inflammation thus contributes to pain, a cardinal feature of inflammation [67, 68]. While the pain results from inflammation are adaptive, it still needs to be reduced; if not, ongoing inflammation may cause central sensitization, modify pain perception thresholds, and transit acute localized pain into chronic widespread pain [69, 70]. Another possible mechanism for the relationship between using solid fuels and pain involves oxidative dysfunction. Some pollutants, such as nitrogen oxides and carbon monoxide, contribute to the intracellular formation of free radicals and cause oxidative damage to DNA, lipids, proteins, and cells [71, 72]. Previous studies [39, 73] supported the potential role of oxidative stress and related structures in the pathogenesis of migraine. Mounting evidence [73, 74] has also revealed that oxidative dysfunction is critically involved in the induction and maintenance of neuropathic pain. In addition, pain comorbidities may explain the link between cooking with solid fuels and pain. Exposure to solid fuels has been associated with a series of health consequences, including arthritis [11], cognitive decline [12], and depression [13]. Much evidence from epidemiological and animal models shows that patients with chronic pain often coexist with the above diseases [20, 51, 75], and body pain frequently presents as a result of a disease or an injury. Our study further explored a more precise and individual reflection of pain and observed that pain localized in the musculoskeletal system, including arm/hands, buttock, and legs/feet, exhibited the most prominent associations. Several potential mechanisms may explain the association, including systemic inflammation, changes in pain intensity, reduced perfusion, and malnutrition of tissues [26, 34]. We also observed a positive association between solid fuel use and pain in other body parts like the head, chest, and hips, and the mechanisms may differ from location to location. As we breathe, the pollutants produced by burning fossil fuels may enter different organs and provoke inflammatory processes that may cause pain in specific areas, such as headache via the nerves [37], chest pain via the cardiovascular system [40], or abdominal pain via the gut-lung axis [44]. Significantly, various pain syndromes may point towards similar underlying pathology and have a cumulative effect that subsequently contributes

Table 3: Association of fuel types and fuel transitions with short-term trajectories of body pain sites from 2011 to 2018.

Variables	Model 1 IRR (95% CI)	Model 2 IRR (95% CI)	Model 3 IRR (95% CI)
Fuel types			
Cooking fuels			
Clean fuels	Reference	Reference	Reference
Solid fuels	1.76 (1.60 to 1.93)***	1.30 (1.21 to 1.39)***	1.25 (1.16 to 1.34)***
Time			
2011	Reference	Reference	Reference
2015	1.35 (1.24 to 1.48)***	2.54 (2.30 to 2.80)***	2.54 (2.30 to 2.80)***
2018	2.81 (2.60 to 3.05)***	6.25 (5.78 to 6.75)***	6.28 (5.81 to 6.78)***
Interaction terms			
2015 × solid fuels	0.88 (0.80 to 0.98)*	1.02 (0.91 to 1.15)	1.02 (0.90 to 1.14)
2018 × solid fuels	0.70 (0.64 to 0.77)***	0.79 (0.72 to 0.87)***	0.78 (0.71 to 0.86)***
Transition types			
Fuel transitions			
Always clean	Reference	Reference	Reference
Solid to clean	1.63 (1.45 to 1.82)***	1.27 (1.17 to 1.38)***	1.22 (1.13 to 1.33)***
Clean to solid	1.53 (1.23 to 1.90)***	1.28 (1.09 to 1.50)**	1.24 (1.06 to 1.45)***
Always solid	2.09 (1.88 to 2.33)***	1.42 (1.31 to 1.53)***	1.37 (1.26 to 1.48)**
Time			
2011	Reference	Reference	Reference
2015	1.35 (1.23 to 1.49)***	2.51 (2.26 to 2.79)***	2.50 (2.25 to 2.78)***
2018	2.89 (2.65 to 3.15)***	6.31 (5.81 to 6.85)***	6.33 (5.83 to 6.88)***
Interaction terms			
2015 × solid to clean	0.89 (0.78 to 1.01)	0.98 (0.84 to 1.13)	0.98 (0.84 to 1.13)
2015 × clean to solid	1.00 (0.78 to 1.28)	1.07 (0.80 to 1.44)	1.09 (0.81 to 1.46)
2015 × always solid	0.88 (0.78 to 0.99)*	1.07 (0.93 to 1.23)	1.06 (0.93 to 1.22)
2018 × solid to clean	0.71 (0.63 to 0.79)***	0.78 (0.69 to 0.88)***	0.78 (0.69 to 0.87)***
2018 × clean to solid	0.80 (0.64 to 1.01)	0.89 (0.70 to 1.12)	0.89 (0.70 to 1.13)
2018 × always solid	0.67 (0.60 to 0.74)***	0.77 (0.69 to 0.86)***	0.76 (0.68 to 0.85)***

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. Abbreviations: IRR: incidence rate ratio; CI: confidence interval. Model 1 adjusted for age (continuous), gender (male or female), marital status (unmarried or married), residence (rural or urban), education level (less than lower secondary, upper secondary, and vocational training or tertiary), and currently working (yes or no). Model 2 additionally adjusted for smoking status (never or current/ever), alcohol consumption (never or current/ever), the number of diseases (0, 1, >1), and the number of pain sites at baseline (continuous). Model 3 further adjusted for household consumption expenditure (in quartiles), number of people living in the household (1, 2, >2), and heating fuels (clean fuels, solid fuels, or other fuels).

to widespread pain [47, 76]. Considering that the causal mechanisms are still hypothetical and pain is highly complex, more research is warranted to confirm.

Prior literature reported that individual and household characteristics could affect susceptibility to the health effects of using polluting fuels [53, 77, 78]. The current study also observed inconsistent associations between cooking with solid fuels and the number of pain sites across gender, currently working, smoking status, number of diseases, and household consumption expenditure. Compared with females, males were more susceptible to the effect of cooking with solid fuels on pain. One possible explanation is that females are more often exposed to solid fuels for cooking [79] and more frequently display pain symptoms [80]; this may mix the findings and contribute to a statistical difference. We also found that those not having jobs were more likely to be affected by the effect of cooking with solid fuels on pain than those having jobs, potentially due to having meals at home more frequently. Moreover, our study indicated that ever or current smokers were more likely to be affected by the fuel-pain association than nonsmokers. This may also partly explain the observed sex difference, with smokers almost being males. A smoking difference may be due to the additive effect of harmful pollutants. Studies found that smoking increased the odds of chronic pain onset and progression [81], and recurrent nicotine exposure resulted in physiological tolerance, leading to reduced pain inhibition and more excellent pain perception [82]. Strangely, those with the highest household consumption expenditure tended to be more susceptible to the hazardous effects of using solid fuels. As household consumption

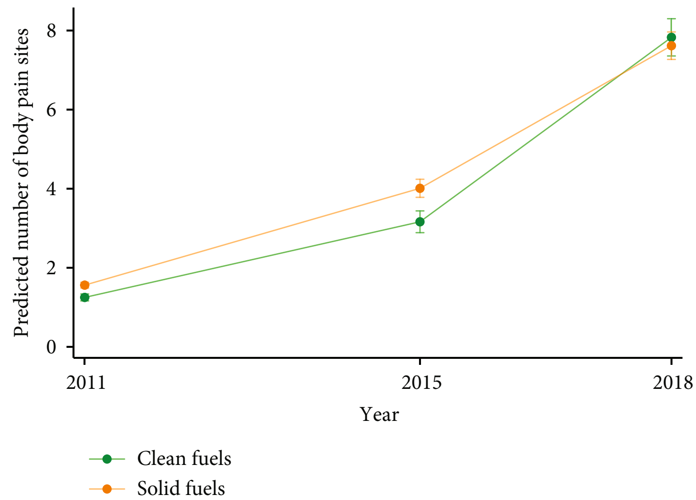

FIGURE 2: Association between cooking fuels and short-term trajectories of body pain in 2011-2018.

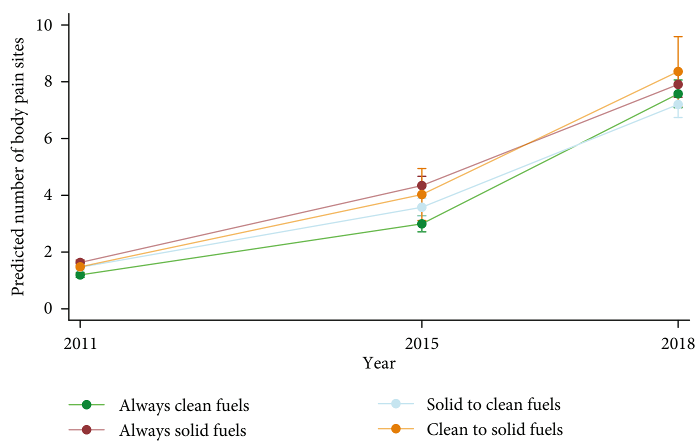

FIGURE 3: Association between cooking fuel transitions and short-term trajectories of body pain in 2011-2018.

expenditure reflects household income to some extent, this finding may be attributed to the higher impact of income on pain than using solid fuels [83], with the group with the lowest level of household consumption expenditure having the most pain sites among those using clean fuels. Similarly, the more prominent association in those with one disease rather than those with multimorbidity or none may also occur due to the more significant effect of pain-comorbidity on pain [84]. A study showed that the number of pain sites tends to be stable in the general population [47]; thus, for those with multimorbidity that had the most pain sites when using clean fuels, it is hard to develop more sites.

Pain has often been deemed a state that will be stable, improved, or worsening; thus, repeated data measurements were used to investigate the development and maintenance of pain. Contrary to our expectations, using solid fuels was associated with a slower rate of pain site increase over seven years. Indeed, chronic pain tends to amplify over time, but the number of pain sites that most subjects can develop is stable [47]. This may explain the above findings. In the present study, those using clean fuels for cooking had fewer pain sites than those using solid fuels, which meant that the former was faster to reach the peak. On the other hand, those exposed to solid fuels were close to the top, which may limit the speed of pain development. The current study observed that the changes in pain in different groups from 2015 to 2018 tend to be similar, suggesting that other risk factors that did not occur may exist. Future studies can explore the trajectory of pain from a lifecycle perspective and a deeper understanding of the mechanisms of pain. Furthermore, when fuel switching was considered, pain trajectories became more complicated. The group transiting from clean to solid fuels had a faster rate of pain site increase than those from solid to clean fuels over seven years, further confirming the harmful effect of using solid fuels. Generally, household energy choices should change from solid to cleaner fuels as economic conditions improve. However, the combined use of multiple energy is still common in rural homes in China [85]. This phenomenon is attributed to poor economic conditions and is associated with specific cultural contexts [86]. China is in an earlier stage of epidemiological transition than high-income countries, which may make people's behaviors in various patterns. Regardless, our data showed a nonconventional energy transition and highlighted its impact on pain; thus, it is important to explore further why such a strange way of switching fuels and take measures to help clean fuel spread.

The study's strengths are the availability of data regarding fuel transition, repeated pain measurements, and systematic investigation of pain (number of pain sites and locations). However, there are several limitations to this study. First, the major limitation of this study was based on the self-reported information on body pain. To confirm the robustness of our findings, we used pain data from three repeated measurements (in 2011, 2015, and 2018) and added the analyses on the relationship between household use of polluting cooking fuels and different regional pain sites to get more information about the underlying mechanism of pathogenesis. The etiology and prognosis of pain are complex and believed to involve interactions between biological, psychological, and social. Thus, future research should define the pain via doctors' diagnoses or using a body map for participants to report the anatomical localization of their pain to understand the underlying pathogenic mechanism. Second, the pain assessment in the second survey (in 2013), which asked participants about yesterday's pain, differs from other survey years. Thus, the information on pain in the first (in 2011), third (in 2015), and fourth (in 2018) surveys were included in the study, leading to a large time interval between each pain assessment. Collecting continuous annual data on pain, which can help describe the trajectory of pain development, is better. Third, this study relied on one simple item to measure pain and did not provide information on the causes of pain, limiting us from exploring more pain traits and getting clinical implications, such as pain level, duration, and frequency. Fourth, the follow-up time in our study was relatively short, so it was hard to depict the life-course pain trajectories. For example, our study indicated that the number of pain sites might increase with time and stabilize at a level, but we failed to observe the subsequent development of pain. More longitudinal studies with longer observation times are needed to confirm our findings. Fifth, a few important risk factors were not assessed in this study, including ergonomic postures, stove types, duration of use, and outdoor air quality due to limited data. These risk factors need further verification in future research.

5. Conclusions

In summary, this study provided new evidence linking using solid fuels for cooking with more pain sites, but a slower rate of pain sites increases. Males, smokers, those not having jobs, those with the highest household consumption expenditure, and those with one chronic disease responded more strongly to the harmful effects of indoor air pollution. When fuel switching was further considered, our study observed a nonconventional energy transition from clean to solid fuels and highlighted its impact on pain. Compared with those who persistently used clean fuels for cooking, the number of pain sites increased by 10% in participants who were transiting from using solid to clean fuels, by 21% in those transiting from cooking with clean to solid fuels, and by 25% among those persistent using solid fuels for cooking. Deeper explores why such a strange way of switching fuels is important and takes measures to help clean fuels spread.

Data Availability

All data in CHARLS are maintained at Peking University and will be accessible publicly. The datasets generated during the current study were from the Harmonized CHARLS dataset and Codebook (http://charls.pku.edu.cn/).

Ethical Approval

The data collection in CHARLS was ethically approved by the Biomedical Ethics Review Committee of Peking University (approval number: IRB00001052-11015).

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' Contributions

Yi Zhu was responsible for conceptualization, methodology, formal analysis, writing the original draft, reviewing, and editing. Lijin Chen was responsible for formal analysis, writing the original draft, reviewing, and editing. Honghong Feng was responsible for formal analysis, writing the original draft, reviewing, and editing. Esthefany Xu Zheng was responsible for writing, reviewing, and editing. Yixiang Huang was responsible for conceptualization, supervision, writing, reviewing, and editing. Yi Zhu and Lijin Chen contributed equally as co-first authors.

Supplementary Materials

A series of exploratory and sensitive analyses were performed to assess the robustness of the primary findings. The details of these results were provided in the supplementary part. We also briefly introduced the GEE model. The title of the additional content is as follows. (1) Supplementary Methods. (2) Table S1: model selection. (3) Table S2: correlation matrix. (4) Table S3: distribution of cooking fuel types and fuel transitions from 2011 to 2018. (5) Table S4a: interaction effects of fuel types and potential moderators on body pain sites. (6) Table S4b: interaction effects of fuel types and potential moderators on body pain sites (continued). (7) Table S5: distribution of the number of pain sites from 2011 to 2018 by cooking fuel types. (8) Table S6: baseline characteristics across the study sample and excluded individuals. (9) Table S7: association of fuel types and fuel transitions with body pain sites in imputed dataset. (10) Table S8: association of fuel types and fuel transitions with short-term trajectories of body pain in the imputed dataset. (11) Table S9: association of fuel types and fuel transitions with body pain sites excluding those having chronic diseases at baseline

($N = 2947$). (12) Table S10: association of fuel types and fuel transitions with short-term trajectories of body pain excluding those having chronic diseases at baseline ($N = 2947$). (13) Table S11: association of fuel types and fuel transitions with body pain sites with additional adjustment for physical activity at baseline ($N = 3621$). (14) Table S12: association of fuel types and fuel transitions with short-term trajectories of body pain with additional adjustment for physical activity at baseline ($N = 3621$). (15) Table S13: association between fuel types and body pain sites through different working correlation matrix. (16) Figure S1: subgroup analyses of the association between cooking fuels and the number of body pain sites. (17) Figure S2: association of cooking fuels with specific pain sites. *(Supplementary Materials)*

References

[1] WHO, "The Global Health Observatory of household air pollution data," 2020, https://www.who.int/data/gho/data/themes/air-pollution.

[2] E. A. Marais and C. Wiedinmyer, "Air quality impact of diffuse and inefficient combustion emissions in Africa (DICE-Africa)," *Environmental Science & Technology*, vol. 50, no. 19, pp. 10739–10745, 2016.

[3] A. S. Bockarie, E. A. Marais, and A. R. MacKenzie, "Air pollution and climate forcing of the charcoal industry in Africa," *Environmental Science & Technology*, vol. 54, no. 21, pp. 13429–13438, 2020.

[4] Y. Chen, H. Shen, K. R. Smith et al., "Estimating household air pollution exposures and health impacts from space heating in rural China," *Environment International*, vol. 119, pp. 117–124, 2018.

[5] Y. Zhao, R. Atun, B. Oldenburg et al., "Physical multimorbidity, health service use, and catastrophic health expenditure by socioeconomic groups in China: an analysis of population-based panel data," *The Lancet Global Health*, vol. 8, no. 6, pp. e840–e849, 2020.

[6] GBD 2019 Risk Factors Collaborators, "Global burden of 87 risk factors in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019," *Lancet*, vol. 396, no. 10258, pp. 1223–1249, 2020.

[7] HEI, *State of Global Air 2020. Special Report*, Health Effects Institute, Boston, MA, 2020.

[8] H. Hussein, M. Shamsipour, M. Yunesian, M. S. Hasanvand, T. Mahamudu, and A. Fotouhi, "Fuel type use and risk of respiratory symptoms: a cohort study of infants in the northern region of Ghana," *Science of The Total Environment*, vol. 755, Part 1, article 142501, 2021.

[9] L. Lin, H. H. Wang, Y. Liu, C. Lu, W. Chen, and V. Y. Guo, "Indoor solid fuel use for heating and cooking with blood pressure and hypertension: a cross-sectional study among middle-aged and older adults in China," *Indoor Air*, vol. 31, no. 6, pp. 2158–2166, 2021.

[10] S. Qiu, X. Chen, X. Chen et al., "Solid fuel use, socioeconomic indicators and risk of cardiovascular diseases and all-cause mortality: a prospective cohort study in a rural area of Sichuan, China," *International Journal of Epidemiology*, vol. 51, no. 2, pp. 501–513, 2022.

[11] Y. Deng, Q. Gao, T. Yang, B. Wu, Y. Liu, and R. Liu, "Indoor solid fuel use and incident arthritis among middle-aged and older adults in rural China: a nationwide population-based cohort study," *Science of the Total Environment*, vol. 772, article 145395, 2021.

[12] J. L. Saenz, S. D. Adar, Y. S. Zhang et al., "Household use of polluting cooking fuels and late-life cognitive function: a harmonized analysis of India, Mexico, and China," *Environment International*, vol. 156, article 106722, 2021.

[13] J. Shao, T. Ge, Y. Liu, Z. Zhao, and Y. Xia, "Longitudinal associations between household solid fuel use and depression in middle-aged and older Chinese population: a cohort study," *Ecotoxicology and Environmental Safety*, vol. 209, article 111833, 2021.

[14] A. Vodonos, V. Novack, Y. Zlotnik, and G. Ifergane, "Ambient air pollution, weather and daily emergency department visits for headache," *Cephalalgia*, vol. 35, no. 12, pp. 1085–1091, 2015.

[15] C. C. Chen and C. Y. Yang, "Association between fine particulate air pollution and hospital admissions for chest pain in a subtropical city: Taipei, Taiwan," *Journal of Toxicology and Environmental Health, Part A*, vol. 80, no. 23-24, pp. 1269–1275, 2017.

[16] M. Yang, K. Wu, Q. Wu et al., "A systematic review and meta-analysis of air pollution and angina pectoris attacks: identification of hazardous pollutant, short-term effect, and vulnerable population," *Environmental Science and Pollution Research International*, vol. 30, no. 12, pp. 32246–32254, 2023.

[17] S. N. Raja, D. B. Carr, M. Cohen et al., "The revised International Association for the Study of Pain definition of pain: concepts, challenges, and compromises," *Pain*, vol. 161, no. 9, pp. 1976–1982, 2020.

[18] H. Lee, M. Hübscher, G. L. Moseley et al., "How does pain lead to disability? A systematic review and meta-analysis of mediation studies in people with back and neck pain," *Pain*, vol. 156, no. 6, pp. 988–997, 2015.

[19] G. van der Leeuw, L. H. Eggermont, L. Shi et al., "Pain and cognitive function among older adults living in the community," *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, vol. 71, no. 3, pp. 398–405, 2016.

[20] M. M. J. G. Gerrits, P. van Oppen, H. W. J. van Marwijk, B. W. J. H. Penninx, and H. E. van der Horst, "Pain and the onset of depressive and anxiety disorders," *Pain*, vol. 155, no. 1, pp. 53–59, 2014.

[21] S. P. Cohen, L. Vase, and W. M. Hooten, "Chronic pain: an update on burden, best practices, and new advances," *Lancet*, vol. 397, no. 10289, pp. 2082–2097, 2021.

[22] J. C. Landefeld, C. Miaskowski, L. Tieu et al., "Characteristics and factors associated with pain in older homeless individuals: results from the health outcomes in people experiencing homelessness in older middle age (HOPE HOME) study," *The Journal of Pain*, vol. 18, no. 9, pp. 1036–1045, 2017.

[23] 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*, vol. 396, no. 10258, pp. 1204–1222, 2020.

[24] J. L. St Sauver, D. O. Warner, B. P. Yawn et al., "Why patients visit their doctors: assessing the most prevalent conditions in a defined American population," *Mayo Clinic Proceedings*, vol. 88, no. 1, pp. 56–67, 2013.

[25] R. D. Treede, W. Rief, A. Barke et al., "Chronic pain as a symptom or a disease: the IASP classification of chronic pain for the

international classification of diseases (ICD-11)," *Pain*, vol. 160, no. 1, pp. 19–27, 2019.

[26] D. Matre, J. O. Christensen, P. J. Mork, P. Ferreira, T. Sand, and K. B. Nilsen, "Shift work, inflammation and musculoskeletal pain-the HUNT study," *Occupational Medicine*, vol. 71, no. 9, pp. 422–427, 2021.

[27] N. Ziadé, M. Bouzamel, M. Mrad-Nakhlé et al., "Prospective correlational time-series analysis of the influence of weather and air pollution on joint pain in chronic rheumatic diseases," *Clinical Rheumatology*, vol. 40, no. 10, pp. 3929–3940, 2021.

[28] C. Yao, Y. Zhang, P. Lu et al., "Exploring the bidirectional relationship between pain and mental disorders: a comprehensive Mendelian randomization study," *The Journal of Headache and Pain*, vol. 24, no. 1, p. 82, 2023.

[29] I. Kuorinka, B. Jonsson, A. Kilbom et al., "Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms," *Applied Ergonomics*, vol. 18, no. 3, pp. 233–237, 1987.

[30] D. Prada, J. Zhong, E. Colicino et al., "Association of air particulate pollution with bone loss over time and bone fracture risk: analysis of data from two independent studies," *The Lancet Planetary Health*, vol. 1, no. 8, pp. e337–e347, 2017.

[31] Y. Yang, R. Li, M. Cai et al., "Ambient air pollution, bone mineral density and osteoporosis: results from a national population-based cohort study," *Chemosphere*, vol. 310, article 136871, 2023.

[32] R. Rückerl, A. Schneider, S. Breitner, J. Cyrys, and A. Peters, "Health effects of particulate air pollution: a review of epidemiological evidence," *Inhalation Toxicology*, vol. 23, no. 10, pp. 555–592, 2011.

[33] M. A. Koop, I. J. Lutke Schipholt, G. G. M. Scholten-Peeters, and M. W. Coppieters, "Identifying the most important confounders when assessing the association between low-grade systemic inflammation and musculoskeletal pain: a modified Delphi study," *Pain Medicine*, vol. 22, no. 11, pp. 2661–2669, 2021.

[34] C. Pisinger, M. Aadahl, U. Toft, H. Birke, J. Zytphen-Adeler, and T. Jørgensen, "The association between active and passive smoking and frequent pain in a general population," *European Journal of Pain*, vol. 15, no. 1, pp. 77–83, 2011.

[35] Y. Dai, J. Huang, Q. Hu, L. Huang, J. Wu, and J. Hu, "Association of cigarette smoking with risk of chronic musculoskeletal pain: a meta-analysis," *Pain Physician*, vol. 24, no. 8, pp. 495–506, 2021.

[36] E. Díaz, T. Smith-Sivertsen, D. Pope et al., "Eye discomfort, headache and back pain among Mayan Guatemalan women taking part in a randomised stove intervention trial," *Journal of Epidemiology & Community Health*, vol. 61, no. 1, pp. 74–79, 2007.

[37] S. Louis, A. K. Carlson, A. Suresh et al., "Impacts of climate change and air pollution on neurologic health, disease, and practice: a scoping review," *Neurology*, vol. 100, no. 10, pp. 474–483, 2023.

[38] S. Ye, S. Li, Y. Ma et al., "Ambient NO_2 exposure induces migraine in rats: evidence, mechanisms and interventions," *Science of The Total Environment*, vol. 844, article 157102, 2022.

[39] J. M. Borkum, "Migraine triggers and oxidative stress: a narrative review and synthesis," *Headache*, vol. 56, no. 1, pp. 12–35, 2016.

[40] G. Cesaroni, F. Forastiere, M. Stafoggia et al., "Long term exposure to ambient air pollution and incidence of acute coronary events: prospective cohort study and meta-analysis in 11 European cohorts from the ESCAPE project," *BMJ*, vol. 348, article f7412, 2014.

[41] R. D. Brook, S. Rajagopalan, C. A. Pope 3rd et al., "Particulate matter air pollution and cardiovascular disease: an update to the scientific statement from the American Heart Association," *Circulation*, vol. 121, no. 21, pp. 2331–2378, 2010.

[42] G. G. Kaplan, M. Szyszkowicz, J. Fichna et al., "Non-specific abdominal pain and air pollution: a novel association," *PLoS One*, vol. 7, no. 10, article e47669, 2012.

[43] Y. Liu, Y. Jiang, M. Wu, S. Muheyat, D. Yao, and X. Jin, "Short-term effects of ambient air pollution on daily emergency room visits for abdominal pain: a time-series study in Wuhan, China," *Environmental Science and Pollution Research*, vol. 29, no. 27, pp. 40643–40653, 2022.

[44] L. Keulers, A. Dehghani, L. Knippels et al., "Probiotics, prebiotics, and synbiotics to prevent or combat air pollution consequences: the gut-lung axis," *Environmental Pollution*, vol. 302, article 119066, 2022.

[45] L. A. Beamish, A. R. Osornio-Vargas, and E. Wine, "Air pollution: an environmental factor contributing to intestinal disease," *Journal of Crohn's & Colitis*, vol. 5, no. 4, pp. 279–286, 2011.

[46] K. Walker-Bone, I. Reading, D. Coggon, C. Cooper, and K. T. Palmer, "The anatomical pattern and determinants of pain in the neck and upper limbs: an epidemiologic study," *Pain*, vol. 109, no. 1, pp. 45–51, 2004.

[47] T. Landmark, P. Romundstad, S. Butler, S. Kaasa, and P. Borchgrevink, "Development and course of chronic widespread pain: the role of time and pain characteristics (the HUNT pain study)," *Pain*, vol. 160, no. 9, pp. 1976–1981, 2019.

[48] J. Hu, A. V. Bortsov, L. Ballina et al., "Chronic widespread pain after motor vehicle collision typically occurs through immediate development and nonrecovery: results of an emergency department-based cohort study," *Pain*, vol. 157, no. 2, pp. 438–444, 2016.

[49] C. J. Woolf, "Central sensitization: implications for the diagnosis and treatment of pain," *Pain*, vol. 152, no. 3, pp. S2–S15, 2011.

[50] Y. Zhao, Y. Hu, J. P. Smith, J. Strauss, and G. Yang, "Cohort profile: the China Health and Retirement Longitudinal Study (CHARLS)," *International Journal of Epidemiology*, vol. 43, no. 1, pp. 61–68, 2014.

[51] Y. Luo, Z. Liu, L. Yang et al., "Association of body pain and chronic disease: evidence from a 7-year population-based study in China," *Regional Anesthesia and Pain Medicine*, vol. 46, no. 9, pp. 745–751, 2021.

[52] E. Widerström-Noga, F. Biering-Sørensen, T. Bryce et al., "The international spinal cord injury pain basic data set," *Spinal Cord*, vol. 46, no. 12, pp. 818–823, 2008.

[53] L. Cao, Z. Zhao, C. Ji, and Y. Xia, "Association between solid fuel use and cognitive impairment: a cross-sectional and follow-up study in a middle-aged and older Chinese population," *Environment International*, vol. 146, article 106251, 2021.

[54] W. Chen, X. Wang, J. Chen et al., "Household air pollution, adherence to a healthy lifestyle, and risk of cardiometabolic multimorbidity: results from the China health and retirement longitudinal study," *Science of The Total Environment*, vol. 855, article 158896, 2023.

[55] M. Y. Wei and K. J. Mukamal, "Multimorbidity, mortality, and long-term physical functioning in 3 prospective cohorts of community-dwelling adults," *American Journal of Epidemiology*, vol. 187, no. 1, pp. 103–112, 2018.

[56] C. Ye, X. Zheng, S. Aihemaitijiang et al., "Sarcopenia and catastrophic health expenditure by socio-economic groups in China: an analysis of household-based panel data," *Journal of Cachexia, Sarcopenia and Muscle*, vol. 13, no. 3, pp. 1938–1947, 2022.

[57] J. Cui and L. Feng, "Correlation structure and model selection for negative binomial distribution in GEE," *Communications in Statistics-Simulation and Computation*, vol. 38, no. 1, pp. 190–197, 2008.

[58] L. K-Y and S. L. Zeger, "Longitudinal data analysis using generalized linear models," *Biometrika*, vol. 73, no. 1, pp. 13–22, 1986.

[59] I. R. White, P. Royston, and A. M. Wood, "Multiple imputation using chained equations: issues and guidance for practice," *Statistics in Medicine*, vol. 30, no. 4, pp. 377–399, 2011.

[60] Z. Li, A. Commodore, S. Hartinger et al., "Biomonitoring human exposure to household air pollution and association with self-reported health symptoms - a stove intervention study in Peru," *Environment International*, vol. 97, pp. 195–203, 2016.

[61] I. Tiwari, R. M. Herr, A. Loerbroks, and S. S. Yamamoto, "Household air pollution and angina pectoris in low- and middle-income countries: cross-sectional evidence from the World Health Survey 2002-2003," *International Journal of Environmental Research and Public Health*, vol. 17, no. 16, 2020.

[62] Y. Chen, G. Shen, W. Liu et al., "Field measurement and estimate of gaseous and particle pollutant emissions from cooking and space heating processes in rural households, northern China," *Atmospheric Environment*, vol. 125, pp. 265–271, 2016.

[63] O. Hahad, J. Lelieveld, F. Birklein, K. Lieb, A. Daiber, and T. Münzel, "Ambient air pollution increases the risk of cerebrovascular and neuropsychiatric disorders through induction of inflammation and oxidative stress," *International Journal of Molecular Sciences*, vol. 21, no. 12, 2020.

[64] C. A. Pope 3rd, A. Bhatnagar, J. P. McCracken, W. Abplanalp, D. J. Conklin, and T. O'Toole, "Exposure to fine particulate air pollution is associated with endothelial injury and systemic inflammation," *Circulation Research*, vol. 119, no. 11, pp. 1204–1214, 2016.

[65] K. M. Smart, C. Blake, A. Staines, and C. Doody, "The discriminative validity of "nociceptive," "peripheral neuropathic," and "central sensitization" as mechanisms-based classifications of musculoskeletal pain," *The Clinical Journal of Pain*, vol. 27, no. 8, pp. 655–663, 2011.

[66] J. M. Zhang and J. An, "Cytokines, inflammation, and pain," *International Anesthesiology Clinics*, vol. 45, no. 2, pp. 27–37, 2007.

[67] M. Matsuda, Y. Huh, and R. R. Ji, "Roles of inflammation, neurogenic inflammation, and neuroinflammation in pain," *Journal of Anesthesia*, vol. 33, no. 1, pp. 131–139, 2019.

[68] C. J. Woolf, "What is this thing called pain?," *The Journal of Clinical Investigation*, vol. 120, no. 11, pp. 3742–3744, 2010.

[69] L. Arendt-Nielsen, C. Fernandez-de-Las-Penas, and T. Graven-Nielsen, "Basic aspects of musculoskeletal pain: from acute to chronic pain," *The Journal of Manual & Manipulative Therapy*, vol. 19, no. 4, pp. 186–193, 2011.

[70] T. Graven-Nielsen and L. Arendt-Nielsen, "Assessment of mechanisms in localized and widespread musculoskeletal pain," *Nature Reviews Rheumatology*, vol. 6, no. 10, pp. 599–606, 2010.

[71] C. A. Piantadosi, "Carbon monoxide, reactive oxygen signaling, and oxidative stress," *Free Radical Biology & Medicine*, vol. 45, no. 5, pp. 562–569, 2008.

[72] W. Yang and S. T. Omaye, "Air pollutants, oxidative stress and human health," *Mutation Research*, vol. 674, no. 1-2, pp. 45–54, 2009.

[73] S. Geyik, E. Altunısık, A. M. Neyal, and S. Taysi, "Oxidative stress and DNA damage in patients with migraine," *The Journal of Headache and Pain*, vol. 17, no. 1, p. 10, 2016.

[74] L. Teixeira-Santos, A. Albino-Teixeira, and D. Pinho, "Neuroinflammation, oxidative stress and their interplay in neuropathic pain: focus on specialized pro-resolving mediators and NADPH oxidase inhibitors as potential therapeutic strategies," *Pharmacological Research*, vol. 162, article 105280, 2020.

[75] L. A. Low, "The impact of pain upon cognition: what have rodent studies told us?," *Pain*, vol. 154, no. 12, pp. 2603–2605, 2013.

[76] S. Neupane, T. Lallukka, O. Pietiläinen, O. Rahkonen, and P. Leino-Arjas, "Trajectories of multisite musculoskeletal pain in midlife: associations with common mental disorders," *European Journal of Pain*, vol. 24, no. 2, pp. 364–373, 2020.

[77] K. H. Chan, M. Yan, D. A. Bennett et al., "Long-term solid fuel use and risks of major eye diseases in China: a population-based cohort study of 486,532 adults," *PLoS Medicine*, vol. 18, no. 7, article e1003716, 2021.

[78] P. Hystad, M. Duong, M. Brauer et al., "Health effects of household solid fuel use: findings from 11 countries within the prospective urban and rural epidemiology study," *Environmental Health Perspectives*, vol. 127, no. 5, article 57003, 2019.

[79] N. Bruce, R. Perez-Padilla, and R. Albalak, "Indoor air pollution in developing countries: a major environmental and public health challenge," *Bulletin of the World Health Organization*, vol. 78, no. 9, pp. 1078–1092, 2000.

[80] K. E. Mansfield, J. Sim, J. L. Jordan, and K. P. Jordan, "A systematic review and meta-analysis of the prevalence of chronic widespread pain in the general population," *Pain*, vol. 157, no. 1, pp. 55–64, 2016.

[81] S. L. Chapman and L. T. Wu, "Associations between cigarette smoking and pain among veterans," *Epidemiologic Reviews*, vol. 37, no. 1, pp. 86–102, 2015.

[82] J. W. Ditre, T. H. Brandon, E. L. Zale, and M. M. Meagher, "Pain, nicotine, and smoking: research findings and mechanistic considerations," *Psychological Bulletin*, vol. 137, no. 6, pp. 1065–1093, 2011.

[83] J. M. Keralis, "Pain and poverty: disparities by poverty level in the experience of pain-related interference," *Pain Medicine*, vol. 22, no. 7, pp. 1532–1538, 2021.

[84] M. C. Bushnell, L. K. Case, M. Ceko et al., "Effect of environment on the long-term consequences of chronic pain," *Pain*, vol. 156, pp. S42–S49, 2015.

[85] X. Zhu, X. Yun, W. Meng et al., "Stacked use and transition trends of rural household energy in mainland China," *Environmental Science & Technology*, vol. 53, no. 1, pp. 521–529, 2019.

[86] B. Hou, H. Liao, J. W. Wang, F. Wang, and H. Zhang, "Cooking fuel decision-making and family structure: a field study in China," *Environmental Science and Pollution Research International*, vol. 26, no. 23, pp. 24050–24061, 2019.