

Relationship between pulmonary function and indoor air pollution from coal combustion among adult residents in an inner-city area of southwest China

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Abstract

Few studies evaluate the amount of particulate matter less than 2.5 mm in diameter (PM_{2.5}) in relation to a change in lung function among adults in a population. The aim of this study was to assess the association of coal as a domestic energy source to pulmonary function in an adult population in inner-city areas of Zunyi city in China where coal use is common. In a cross-sectional study of 104 households, pulmonary function measurements were assessed and compared in 110 coal users and 121 non-coal users (≥ 18 years old) who were all nonsmokers. Several sociodemographic factors were assessed by questionnaire, and ventilatory function measurements including forced vital capacity (FVC), forced expiratory volume in 1 s (FEV₁), the FEV₁/FVC ratio, and peak expiratory flow rate (PEFR) were compared between the 2 groups. The amount of PM_{2.5} was also measured in all residences. There was a significant increase in the relative concentration of PM_{2.5} in the indoor kitchens and living rooms of the coal-exposed group compared to the non-coal-exposed group. In multivariate analysis, current exposure to coal smoke was associated with a 31.7% decrease in FVC, a 42.0% decrease in FEV₁, a 7.46% decrease in the FEV₁/FVC ratio, and a 23.1% decrease in PEFR in adult residents. The slope of lung function decrease for Chinese adults is approximately a 2-L decrease in FVC, a 3-L decrease in FEV₁, and an 8 L/s decrease in PEFR per count per minute of PM_{2.5} exposure. These results demonstrate the harmful effects of indoor air pollution from coal smoke on the lung function of adult residents and emphasize the need for public health efforts to decrease exposure to coal smoke.

Key words: Indoor air pollution; Coal combustion; Lung function; Particulate matter

Introduction

Indoor air pollution (IAP) is the second largest environmental contributor to morbidity worldwide, surpassed only by unsafe water and sanitation (1,2). Exposure to IAP from the combustion of coal and biomass fuels is a significant public health hazard, predominantly affecting poor rural and urban communities in developing countries. Such fuel is the domestic energy source for almost three billion people (3,4), and the resulting smoke strongly contributes to the global burden of mortality, accounting for about 1.6 million of the 59 million deaths annually (5).

Stoves fueled by coal can release 50 times more respiratory irritants during cooking compared to gas stoves, and this leads to high concentrations of air pollutants including carbon monoxide (CO), nitrogen oxide, sulfur dioxide (SO₂), polycyclic aromatic hydrocarbons, and inhalable particulate matter of different sizes

(6), as well as hazardous accessory elements such as As, Cd, Co, and others (7). Although most Chinese cities have plans to eliminate coal use in households, many urban communities continue to rely on coal. In Chinese households that use high-sulfur and high-ash coal (low-rank coal) in stoves with limited ventilation, coal burning for cooking or heating substantially contributes to indoor particulate matter levels (8). Small particulate matter less than 2.5 mm in diameter (PM_{2.5}) has been increasingly related to respiratory and cardiovascular morbidity and mortality (9,10). The adult population, particularly women and the elderly, is particularly vulnerable to these adverse health effects because of their greater exposure to IAP from cooking or heating.

Zunyi city possesses abundant coal reserves, is the city most seriously polluted by acid rain, and has record

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high levels of air pollution in China (Figure 1). In the inner-city areas of Zunyi, biomass fuels have been widely replaced at home by cleaner energy sources, such as kerosene, liquid petroleum, gas, or electricity, but coal is still a major source of fuel for cooking and heating throughout the year, particularly in the winter. These conditions prompted us to investigate the impact of coal use on pulmonary function among adult residents in an inner-city area of Zunyi. The objective of this study was to assess the relationship between pulmonary function changes in the adult population and IAP from coal use in inner-city areas of Zunyi city, Guizhou province, in southwest China.

Material and Methods

Study site

This study was conducted in Zunyi, the largest city in the north of Guizhou province, southwest China. There are 11 inner-city areas in Zunyi: Laocheng (LC) Road, Wangli (WL) Road, Zhonghua (ZH) Road, Nanmenguan (NMG) Road, Yanan (YA) Road, Zhouhuiqiao (ZSQ) Road, Zhongshan (ZS) Road, Beijing (BJ) Road, Shanghai (SH) Road, Xima (XM) Road, and Dalian (DL) Road, covering a wide range of geographic areas in Zunyi city (105 km²) and a total population of more than 110 million. These 11 inner-city areas are homogeneous in terms of lifestyle, education, employment and income, housing, geographical origin of the residents, and effects of air pollution (11).

Zunyi is a traditional industrial city and is the most seriously polluted by acid rain in China (12). The frequency of acid precipitation in Zunyi was above 80%, and the lowest pH value of acid precipitation ever reached was 3.2, which was attributed to excessive coal consumption by local industries and households (13). Coal is the major source of fuel for cooking, baking, and heating in the local households during the winter (14). Cooking is mainly done either indoors, with an open-fire traditional cooking stove in a small kitchen without effective

ventilation, or in an open or closed kitchen adjacent to the living room within the house.

Study population and selection process

The study population was selected by a simple random sampling technique. At the first stage of sampling, because of the relative socioeconomic homogeneity among the 11 inner-city areas, one inner-city area, YA Road, was selected by simple random sampling. At the second stage of sampling, because YA Road included 11 residence communities (the communities of Yanan Road Crossing, Juquange, Leitashan, Shongtao Road, Jiaochangba, Jinyinxincun, Jinshishan, Jueshilandao, Zhenzhu Road, Jinjiang, and Jiancai Road), two residence communities (cluster units), Jiaochangba and Jinshishan, were randomly selected for investigation using the same sampling technique. At the final stage of sampling, households were selected at random using quota sampling. In each selected residence community, the cooking fuel source was identified for each of the households visited, and the interviewer used quota sampling to identify 2 cooking categories that contained 52 households each. The two categories were coal and non-coal (modern energy source) use. The first family was selected by simple random sampling of the residential address number. All adult family members present at the residence who met the inclusion criteria were selected. After that, neighbors living in a residence next door who met the inclusion criteria were recruited and interviewed. If no one was at home, the interviewer returned up to three times before moving to another family next door. If the selected family refused to participate or could not be found, neighbors living in the next residence who met the inclusion criteria were recruited. This procedure was repeated for every house among the selected houses until the targeted number of participants was recruited. The residents were asked to complete the consent form and questionnaire at home.

In the coal-users group, adult residents usually spent their time indoors, especially throughout the winter. The



Figure 1. Map of the selected area (Zunyi city) in Guizhou province, China.

participants of the comparison group not using coal were selected by simple random sampling from the people using modern energy sources. Only nonsmokers identified by questionnaire were included in this study in YA Road, in the city of Zunyi. All respiratory measurements were performed during the winter (from October 2011 to March 2012).

Inclusion criteria for the community studied were 1) no factories or plants within the selected community and 2) eligible residents must be 18 years and older (men and women) and have lived within YA Road in Zunyi city for more than 3 years.

Measurement of pulmonary function

Lung function was examined by measuring forced vital capacity (FVC), forced expiratory volume in 1 s (FEV₁), FEV₁/FVC, and peak expiratory flow rate (PEFR), according to standard guidelines (15) using a portable electronic FGC-A+ spirometer (Anhui Institute of Electronic Science, China). The participants were asked to sit in an upright position with both feet flat on the ground. They were instructed to inhale completely, place the meter in their mouth, and to exhale with maximal force as soon as their lips were sealed around the mouthpiece, while maintaining an upright position. An investigator demonstrated the maneuver. Based on guidelines of the American Thoracic Society (16), maneuvers were only accepted if they had low back-extrapolated volume (<5% of the FVC and <0.15 L), both the FVC and FEV₁ were within 0.20 L of the best effort FVC and FEV₁, and there was a low volume accumulated at the end of the effort. Each subject was tested on three expiratory maneuvers. Data analysis was conducted on the largest FVC of the two curves, the largest FEV₁, the ratio of the largest FEV₁ to the largest FVC, and the largest PEFR.

Measurement of pollutants

During cooking, air pollutant concentrations of particulate matter with an aerodynamic diameter less than 2.5 mm (PM_{2.5}) were measured. During cooking with coal and non-coal fuels in the selected households, indoor concentrations of air pollutant were monitored in the kitchen and living room while outdoor concentrations were also measured. All air sampling was carried out at a height of 1.2-1.5 m from the floor of each household. Three measurements were obtained from 3 sampling sites at a distance of 1 m from the center of the cooking stove inside the kitchen. Three measurements were obtained from 3 random sampling sites inside the living room at least 3 m from the kitchen. Three outdoor measurements were obtained as environmental control samples from 3 random sampling sites outside the study household at least 20 m from the household.

To measure PM_{2.5} concentrations inside and outside the households, we used a digital dust monitor (LD-3K; Sibata Scientific Technology Inc., Japan; Figure 2), which

is a portable monitor based on the light-scattering principle, with a laser diode as the light source. The monitor determines the relative concentration of PM_{2.5} by measuring the intensity of the laser beam scattered by particles. The advantage of measuring PM_{2.5} relative concentration with the LD-3K fine dust monitor was that it allowed an analysis of concentration level (high or low), namely, a relative comparison (screening) and an analysis of variation with time (17). The relative concentration is reported as counts per minute (cpm). To determine the cpm, the following equation was used: $cpm = \text{count value}/\text{measuring time (in min)}$. Each measurement was maintained for over 1 min, and three readings were taken for each measurement to calculate the mean relative concentration. There was an interval period of 1 min between the 3 measurements of PM_{2.5} in the kitchen, living room, or outdoors, whereas the interval period for measurements between the kitchen, living room, and outdoors was 5 min in each house.

Data analysis

Data analysis was carried out using the Statistical Package for Social Sciences version 15.0 (SPSS Inc., USA). Pearson's chi-square tests were used to compare categorical characteristics such as gender, respiratory tract infections, and environmental tobacco smoke exposure (defined by the presence of a smoker in the household) in the two groups. Student *t*-tests were used to compare differences in baseline characteristics (age, height, weight, number of rooms, and number of persons in the household) and pulmonary function indices, as well as indoor and outdoor PM_{2.5} relative concentrations between cooking fuel categories for adult participants. Multivariate linear regression analysis was used to assess the association between coal combustion and pulmonary function with other sociodemographic factors (e.g., age, gender, height, and exposure to tobacco smoke, etc.) as variable controls. A value of $P < 0.05$ was considered to be significant for all analyses.

Results

Among the 104 households in the study, we collected data from a total of 231 adult individuals (of 254 available participants); based on their energy source, 110 participants were placed in the coal-exposed group, and 121 participants were selected as the control group. All participants performed acceptable spirometry measurements. PM_{2.5} relative concentration during cooking was measured in 52 households in the coal-exposed group and 52 households in the unexposed group. The individuals in the coal-exposed and unexposed groups were similar regarding demographic characteristics: 64.5% were female (exposed) vs 57.9% (unexposed), with age ranges of 20 to 74 (exposed) and 19 to 71 years (unexposed); the mean heights were 163.7 ± 6.6 cm for coal-exposed individuals

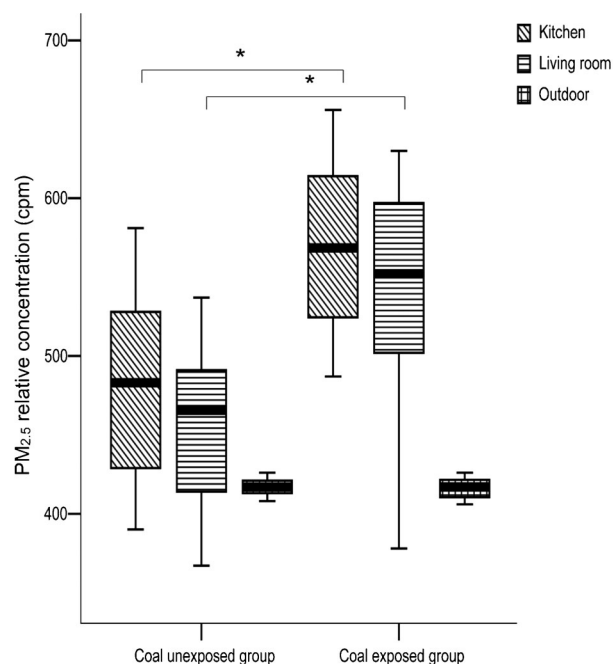


Figure 2. PM_{2.5} relative concentration according to coal exposed and unexposed groups. * $P < 0.05$, t -test.

and 164.8 ± 6.8 cm for unexposed individuals; and the mean weights were 61.1 ± 7.1 kg and 62.6 ± 7.5 kg for coal-exposed and unexposed individuals, respectively. There was an indication of an imbalance in the two groups regarding the number of persons living in the home ($P = 0.053$). Significant differences were present for the number of rooms in the home ($P < 0.05$) and for individuals who had recurrent pulmonary tract infections (30.9% in exposed vs 13.2% in unexposed groups, Table 1).

For all pulmonary function test parameters (FVC, FEV₁, FEV₁/FVC, and PEFR), highly significant differences ($P < 0.0001$) were observed between coal-exposed and unexposed individuals, with mean values lower in those exposed to coal (Table 1). The indoor and outdoor PM_{2.5} relative concentrations during the cooking period in the coal-exposed and unexposed groups were 569.5 ± 50.1 vs 477.0 ± 58.5 cpm (kitchen), 543.2 ± 65.0 vs 452.7 ± 51.2 cpm (living room), and 416.2 ± 5.9 vs 417.0 ± 5.1 cpm (outdoors), respectively. Values of PM_{2.5} for each group are shown in Figure 2. When the indoor and outdoor concentrations of gaseous pollutant in coal-exposed and unexposed groups were compared, the relative concentrations of PM_{2.5} in the kitchen and living room during coal combustion were significantly higher than during non-coal combustion ($P < 0.0001$), but this was not the case for outdoor concentrations. During coal combustion, the relative concentration of PM_{2.5} in the kitchen was also significantly higher than in the living room and outdoors ($P < 0.0001$).

Linear regression analysis was used for describing the relationship between coal use and pulmonary function measurements while controlling for the other relevant factors associated with pulmonary function. In regression models adjusted for gender, age, weight, height, number of persons living in a home, number of rooms in a home, history of recurrent respiratory tract infections, environmental tobacco smoke exposure, and PM_{2.5} relative concentrations in the kitchen, living room, and outdoors (Tables 2-4), current exposure to coal smoke was associated with a 31.7% decrease in FVC, a 42.0% decrease in FEV₁, a 7.46% decrease in FEV₁/FVC, and a 23.1% decrease in PEFR. In the multivariate models, we found that PM_{2.5} relative concentrations in the kitchen showed a significant effect on FVC, FEV₁, and PEFR. The dose-response relationship between the PM_{2.5} relative concentration in the kitchen and lung function changes is shown in Tables 2, 3, and 5. Our models indicate that there was a 2-L decrease in FVC and a 3-L decrease in FEV₁, as well as an 8 L/s decrease in PEFR per 1 cpm PM_{2.5} exposure among adult participants.

Discussion

In the present study, we performed the first simultaneous evaluation of pulmonary function changes and exposure magnitude in an adult population exposed to coal combustion in China. Our main finding was impaired pulmonary function in both adult males and females who used coal compared to non-users. We also observed a significantly negative association of indoor PM_{2.5} relative concentration from coal combustion with individual lung function. Coal users had comparatively lower pulmonary function values than non-users. The pulmonary function parameters affected by coal use were FVC, FEV₁, FEV₁/FVC, and PEFR. These findings are thought to be related to decreased airflow both in large and small airways (18). This study also demonstrated some deterioration of pulmonary function in the male subjects who came from coal-using families. Coal use is an important factor in pulmonary function deterioration. The mechanism for decreased pulmonary function and impaired pulmonary health among adult individuals exposed to coal combustion is not clear. Coal smoke is thought to facilitate damaging oxidation reactions in the respiratory tract, especially in the lower airways, as well as pulmonary and systemic inflammatory responses, which may account for many of the toxic responses in exposed individuals (19,20).

There is increasing evidence that exposure to coal combustion can affect respiratory health (21-25). In a study conducted in Poland, a highly significant ($P < 0.05$) reduction of FEV₁/FVC values was observed among adult residents (≥ 40 years old) who used coal for cooking or heating (26). A study conducted in a village of western India showed that the use of coal, together with other biomass fuels, was an important factor for pulmonary

Table 1. Demographic and social characteristics, and values for pulmonary function measurements by coal exposure status.

	Coal (+) (n=110)	Coal (-) (n=121)	P
Age (year)	43.7 ± 12.5	40.8 ± 12.4	=0.08
Height (cm)	163.7 ± 6.6	164.8 ± 6.8	=0.23
Weight (kg)	61.1 ± 7.1	62.6 ± 7.5	=0.16
Gender			
Male (%)	35.5	42.1	=0.30
Female (%)	64.5	57.9	
Persons living in a home	4.4 ± 1.2	4.1 ± 1.3	=0.06
Number of rooms in a home	3.9 ± 1.2	4.4 ± 0.9	<0.05
History of recurrent pulmonary tract infections (%)	30.9	13.2	<0.05
Environmental tobacco smoke exposure	32.7	25.6	=0.23
FEV ₁ (L)	2.75 ± 0.56	3.49 ± 0.77	<0.05
FVC (L)	3.22 ± 0.62	3.87 ± 0.70	<0.05
FEV ₁ /FVC (%)	83.13 ± 3.95	91.63 ± 5.46	<0.05
PEFR (L/s)	6.00 ± 0.90	6.80 ± 1.17	<0.05
PM _{2.5} relative concentration in kitchen (cpm)	569.5 ± 50.1	477.0 ± 58.5	<0.05
PM _{2.5} relative concentration in living room (cpm)	543.2 ± 65.0	452.7 ± 51.2	<0.05
Outdoor PM _{2.5} relative concentration (cpm)	416.2 ± 5.9	417.0 ± 5.1	=0.480

Data are reported as means ± SD or otherwise indicated. P values were determined with the independent-samples *t*-test for age, weight, height, persons in a home, number of rooms in a home, pulmonary function tests, and Pearson's chi-square test statistics for gender, history of recurrent pulmonary tract infections, and environmental tobacco smoke exposure. FEV₁: forced expiratory volume in 1 s, FVC: forced vital capacity, and PEFR: peak expiratory flow rate. Particulate matter had an aerodynamic diameter less than 2.5 μm (PM_{2.5}).

function deterioration. FEV₁ (P<0.05), FEV₁ percentage (P<0.01), PEFR (P<0.05), and forced expiratory flow between 25 and 75% (FEF₂₅₋₇₅) values were significantly lower (P<0.01) in coal-using females than in non-users (21). There is consistent evidence (mainly from China), that exposure to coal smoke in the home markedly increases the risk of lung cancer, particularly in women

(27,28). This deterioration of pulmonary function in coal users has been attributed to the amount and concentration of particulate matter and other toxic gases emitted during coal combustion. Similar to previous reports (21,26), we observed highly significant reductions of FVC, FEV₁, FEV₁/FVC, and PEFR in the exposed adults compared to individuals that used non-coal fuels.

Table 2. Estimated parameters and 95% confidence interval (CI) of multivariate linear regression analysis of forced vital capacity (FVC).

Model components	Difference in FVC (L)	95%CI	P
Constant	1.381	-1.930; 4.691	0.409
Coal (yes vs no)	-0.317	-0.396; -0.238	<0.0001
Sex (male vs female)	0.007	-0.053; 0.066	0.826
Age (per 1 year increase)	-0.033	-0.036; -0.030	<0.0001
Height (per 1 cm increase)	-0.001	-0.005; 0.003	0.694
Weight (per 1 kg increase)	0.030	0.016; 0.044	<0.0001
Persons living in a home (per person more)	-0.017	-0.039; 0.005	0.129
Number of rooms in a home (per room more)	-0.006	-0.033; 0.020	0.646
History of recurrent respiratory tract infections (yes vs no)	-0.010	-0.077; 0.057	0.767
Environmental tobacco smoke exposure	-0.009	-0.073; 0.055	0.778
PM _{2.5} relative concentration in kitchen (cpm)	-0.002	-0.004; 0.000	<0.05
PM _{2.5} relative concentration in living room (cpm)	0.001	-0.001; 0.002	0.519
Outdoor PM _{2.5} relative concentration (cpm)	0.000	-0.006; 0.005	0.890

Reference categories are non-coal exposure, females, no history of recurrent respiratory tract infections, and no tobacco smoke exposure.

Table 3. Estimated parameters and 95% confidence interval (CI) of multivariate linear regression analysis of forced expiratory volume (FEV₁) in 1 s.

Model components	Difference in FEV ₁ (L)	95%CI	P
Constant	-12.700	-17.047; -8.352	<0.0001
Coal (yes vs no)	-0.420	-0.525; -0.316	<0.0001
Sex (male vs female)	0.037	-0.041; 0.115	0.348
Age (per 1 year increase)	-0.026	-0.030; -0.022	<0.0001
Height (per 1 cm increase)	0.003	-0.002; 0.009	0.229
Weight (per 1 kg increase)	0.090	0.072; 0.109	<0.0001
Persons living in a home (per person more)	-0.020	-0.049; 0.009	0.169
Number of rooms in a home (per room more)	-0.013	-0.048; 0.021	0.446
History of recurrent respiratory tract infections (yes vs no)	0.000	-0.089; 0.088	0.991
Environmental tobacco smoke exposure	-0.003	-0.086; 0.081	0.950
PM _{2.5} relative concentration in kitchen (cpm)	-0.003	-0.005; 0.000	<0.05
PM _{2.5} relative concentration in living room (cpm)	0.006	-0.004; 0.008	0.561
Outdoor PM _{2.5} relative concentration (cpm)	0.002	-0.005; 0.008	0.658

Reference categories are non-coal exposure, females, no history of recurrent respiratory tract infections, and no tobacco smoke exposure.

Adults exposed to IAP from coal combustion have also been found to have decreased pulmonary function, often associated with chronic obstructive lung disease (26). Given the high proportion of reported recurrent respiratory tract infections and the lower values of some pulmonary function test parameters (e.g., FVC, FEV₁, FEV₁/FVC, and PEFr) that are associated with a higher risk for obstructive lung diseases, we speculate that the risk of chronic obstructive lung disease may be increased among the coal users in our study.

Because the weather is usually cold and cloudy during winter in Zunyi, and also because the Zunyi district has rich deposits of coal, it is natural that there is a large demand for

coal, which is used for heating and cooking in winter. Therefore, coal is the major domestic fuel for most households. Most of the coal used by Zunyi households is a high-sulfur coal with a sulfur content of approximately 3% (13). For many people, the risks to respiratory health may be greater due to exposure to excessively high indoor air pollutants from poorly ventilated household stoves.

Observational studies (4,6,14) that have evaluated the adverse pulmonary health effects of indoor solid fuel (prevalence of respiratory diseases and related symptoms or changes in pulmonary function) used qualitative assessments of exposure, such as fuel type or urban vs rural. Few of those studies also investigated the exposure

Table 4. Estimated parameters and 95% confidence interval (CI) of multivariate linear regression analysis of FEV₁/FVC ratio.

Model components	Difference in FEV ₁ /FVC (%)	95%CI	P
Constant	3.563	-93.878; 101.003	0.942
Coal (yes vs no)	-7.463	-9.797; -5.129	<0.0001
Sex (male vs female)	1.138	-0.603; 2.880	0.198
Age (per 1 year increase)	0.012	-0.076; 0.100	0.785
Height (per 1 cm increase)	0.024	-0.098; 0.145	0.696
Weight (per 1 kg increase)	0.398	-0.011; 0.808	0.056
Persons living in a home (per person more)	0.444	-0.205; 1.093	0.177
Number of rooms in a home (per room more)	-0.100	-0.877; 0.678	0.799
History of recurrent respiratory tract infections (yes vs no)	0.555	-1.418; 2.528	0.578
Environmental tobacco smoke exposure	0.965	-0.912; 2.842	0.310
PM _{2.5} relative concentration in kitchen (cpm)	0.008	-0.044; 0.060	0.757
PM _{2.5} relative concentration in living room (cpm)	-0.002	-0.050; 0.046	0.924
Outdoor PM _{2.5} relative concentration (cpm)	0.036	-0.116; 0.188	0.638

Reference categories are non-coal exposure, females, no history of recurrent respiratory tract infections, and no tobacco smoke exposure.

Table 5. Estimated parameters and 95% confidence interval (CI) of multivariate linear regression analysis of peak expiratory flow rate (PEFR; L/min).

Model components	Difference in PEFR (L/s)	95%CI	P
Constant	8.774	-0.780; 18.327	0.071
Coal (yes vs no)	-0.231	-0.460; -0.002	<0.05
Sex (male vs female)	0.006	-0.165; 0.176	0.948
Age (per 1 year increase)	-0.053	-0.061; -0.044	<0.0001
Height (per 1 cm increase)	0.003	-0.009; 0.015	0.573
Weight (per 1 kg increase)	0.005	-0.035; 0.045	0.798
Persons living in a home (per person more)	0.024	-0.040; 0.087	0.459
Number of rooms in a home (per room more)	0.000	-0.076; 0.076	0.995
History of recurrent respiratory tract infections (yes vs no)	0.075	-0.118; 0.269	0.441
Environmental tobacco smoke exposure	0.004	-0.180; 0.188	0.964
PM _{2.5} relative concentration in kitchen (cpm)	-0.008	-0.013; -0.003	<0.05
PM _{2.5} relative concentration in living room (cpm)	0.002	-0.003; 0.006	0.515
Outdoor PM _{2.5} relative concentration (cpm)	0.007	-0.009; 0.020	0.466

Reference categories are non-coal exposure, females, no history of recurrent respiratory tract infections, and no tobacco smoke exposure.

levels of particulate matter less than 10 mm in diameter (29). No study has yet evaluated all of these effects in the same population and also considered the intensity of exposure to PM_{2.5}. Pollutants from indoor coal combustion are a complicated mixture of aerosol and gases such as particulate matter, SO₂, CO, and others (6). Our study confirmed high concentrations of PM_{2.5} in the kitchen and adjacent living area. The relative concentrations of PM_{2.5} in the kitchen and living room during coal combustion were significantly higher than during non-coal combustion, and linear regression analysis revealed that the PM_{2.5} relative concentration in the kitchen was inversely correlated with pulmonary function test data, which suggests that coal fuel combustion might have contributed to impaired lung function among adult individuals.

In this study, we made an effort to determine the effects of coal use on pulmonary function by adjusting for confounding factors as much as possible. These adjustments were extremely important in such a study because the confounding effects of different factors have been reported to be responsible for some conflicting findings (30). We used multivariate analysis in the present study to control for the effects of gender, age, height, weight, number of persons living in a home, number of rooms in a home, history of recurrent respiratory tract infections, environmental tobacco smoke exposure, and PM_{2.5} relative concentration in the kitchen, living room, and outdoors.

Several limitations of the present study need to be

acknowledged. First, the sample size was relatively small. Second, when interpreting the results of this study, it is important to note that the cross-sectional design limited causal inference. For example, past exposure to coal smoke and recent changes in coal use were not assessed. Third, we cannot comment on the duration of exposure to coal smoke because we could not adequately assess cooking times in households. Furthermore, other factors such as living in a different location, socio-economic status, and outdoor air pollution could have biased our results. Despite these limitations, our study provides an overview of the relationship of pulmonary function changes to IAP from coal use among adult residents in inner-city areas of southwest China.

Prospective studies are needed to assess the long-term effects of coal smoke on lung health among adults. Given the extensive use of coal fuel, public health efforts concerned with respiratory health in the developing world, particularly in China, should address the risks of IAP exposure.

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