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Smoky coal, tobacco smoking, and lung cancer risk in Xuanwei, China

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Abstract

Objectives—Lung cancer rates in Xuanwei are the highest in China. In-home use of smoky coal was associated with lung cancer risk, and the association of smoking and lung cancer risk strengthens after stove improvement. Here, we explored the differential association of tobacco use and lung cancer risk by the intensity, duration, and type of coal used.

Materials and Methods—We conducted a population-based case–control study of 260 male lung cancer cases and 260 age-matched male controls. Odds ratios (OR) and 95% confidence interval (CI) for tobacco use was calculated by conditional logistic regression.

Results—Use of smoky coal was significantly associated with an increased risk of lung cancer risk, and tobacco use was weakly and non-significantly associated with lung cancer risk. When the association was assessed by coal use, the cigarette-lung cancer risk association was null in hazardous coal users and elevated in less hazardous smoky coal users and non-smoky coal users. The risk of lung cancer per cigarette per day decreased as annual use of coal increased (>0-3 tons: OR: 1.09; 95% CI: 1.03-1.17; >3 tons: OR: 0.99; 95% CI: 0.95-1.03). Among more hazardous coal users, attenuation occurs at even low levels of usage (>0-3 tons: OR: 1.02; 95% CI: 0.91-1.14; >3 tons: OR: 0.94; 95% CI: 0.97-1.03).

Conclusion—We found evidence that smoky coal attenuated the tobacco and lung cancer risk association in males that lived in Xuanwei, particularly among users of hazardous coal where even

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low levels of smoky coal attenuated the association. Our results suggest that the adverse effects of tobacco may become more apparent as China's population continues to switch to using cleaner fuels for the home, underscoring the urgent need for smoking cessation in China and elsewhere.

Keywords

Coal; tobacco; lung cancer; indoor air pollution; China; global health; epidemiology

Introduction

In the rural county of Xuanwei, Yunnan Province, in southwest China, lung cancer mortality rates are up to 15 times higher than in the rest of the country (12.3 per 100,000 in China; up to 186.8 per 100,000 in 1975 for men in the three high-mortality communes of Xuanwei)[1]. Much of the lung cancer risk has been attributed to exposure to indoor smoky coal combustion[1-6]. The vast majority of residents in Xuanwei have been farmers, and have traditionally cooked indoors in a firepit with smoky coal (bituminous), smokeless coal (anthracite), or wood in poorly ventilated conditions. This mode of combustion generates airborne particulate matter and a variety of toxins and carcinogens such as polycyclic aromatic hydrocarbons (PAHs)[7]. PAH compounds can be readily absorbed into the body and PAH metabolites have been found in the urine of Xuanwei residents[8]. Inhalation of PAHs has been linked to increasing lung cancer risk[9]. In present day Xuanwei, burning coal still occurs in many rural populations[10].

Previous studies in Xuanwei have identified various risk factors associated with the area's unique home cooking and heating practices. The use of smoky coals with high PAH concentrations substantially increased lung cancer risk[11], and access to better cooking conditions reduced lung cancer risk[4, 5].Worldwide, tobacco smoking is the strongest risk factor for lung cancer where the risk in the heaviest smokers was up to 30-fold higher compared to non-smokers[12]; however, the relative effect of tobacco on lung cancer risk in studies of Xuanwei have been consistently weaker, where the risk in the heaviest smokers was four-fold higher compared to non-smokers[13]. Coal and tobacco contain many known carcinogens[7]. There is significant heterogeneity in the PAH composition in coal[14, 15], even from the same region of the country[11, 16]. Smoking prevalence in the various communes in Xuanwei does not vary significantly[16], suggesting that differences in lung cancer rates geographically could be due to smoky coal use.

Lee et al. reported a stronger association between smoking and lung cancer risk after chimney installation[6].A study that assessed lung cancer risk with diesel exhaust exposure and tobacco smoking noted a diminished relative effect for each exposure in the presence of high levels of the other[17]. These studies suggest an interaction between carcinogens in fossil fuel and tobacco smoke. Further, potential interactions between the intensity of coal used, and coal type with tobacco use remain underexplored. Here, we assess interactions between the intensity and duration of smoky coal, coal type, and tobacco use on lung cancer risk in a population-based case-control study in Xuanwei males.

Materials and Methods

This study population has been described in detail elsewhere[11]. Briefly, this population-based case-control study of lung cancer was conducted in farmers aged 18–85 years, who resided in Xuanwei County for more than one year prior to diagnosis. Cases of lung cancer were diagnosed from November 1985 through February 1990 in one of four hospitals in Xuanwei. These four hospitals account for essentially all lung cancer cases in the region[5]. A total of 500 eligible lung cancer cases were enrolled. After exclusion of 2 cases with incorrect addresses, 498 total cases were identified. Among these, 195 (39%) were diagnosed based on sputum cytology, or pathological findings from needle biopsy, bronchofiberoscopy, or surgery. The remaining cases were diagnosed based on chest X-ray and clinical history.

Controls consisted of a sample of the general population of Xuanwei, selected by a three-stage sampling process. Controls were selected by randomly sampling from the subgroup of people in the small farming group within the larger commune, matching controls to cases based on age (±2 years) and sex.

This study was approved by the Chinese Academy of Preventive Medicine, and was conducted according to the recommendations of the World Medical Association Declaration of Helsinki for human study subject protection. Oral informed consent was obtained from all study subjects.

Subject interviews were conducted at the subject's home (19% for cases and 96% for controls), or in the hospital (81% for cases and 4% for controls). Approximately 17% of interviews were conducted with surrogate respondents. The questionnaire collected information on lifetime history of fuel use, residential history, cooking history, time spent indoors and outdoors, smoking history, environmental tobacco smoke exposure history, medical history, family history of cancer, dietary factors, and socioeconomic status. The participation rates were 100% for cases and 97% for controls. Due to the low prevalence of smoking among females (<1%), this analysis was restricted to males (260 cases and 260 controls).

Interviews collected information about tobacco usage, household fuel usage, source/location of fuel, and tons of fuel purchased annually. They were also asked about any changes in the type of coal that was used and the rate of coal consumption over time. Cigarettes of pipe tobacco were computed by cigarette equivalent (34g) per day.

Lung cancer risk and tobacco use was estimated at different levels of coal use and type. Levels were collapsed when possible to improve statistical stability. Conditional logistic regression models were used to estimate odds ratios (OR) and 95% confidence intervals (95% CI). Tobacco use, cigarettes per day, and year duration (continuous) or smoky coal use, tons per year, and years duration (continuous) were the main predictors of interest; reported ORs were ever, per cigarette/day (ton/year), or year. Models were adjusted for other known risk factors for lung cancer: age, exposure to passive smoking (yes/none), coal mining (ever/never), literacy (yes/no; used as a surrogate for socioeconomic status), history of first-degree relative with lung cancer (yes/no), and non-malignant lung disease history (asthma, tuberculosis, bronchitis, emphysema) (yes/no). Any individuals with missing values for any of the variables included in the model were excluded from the analysis. Cutoff points for stratified analyses were based on the rounded mean among controls. Interaction terms were assessed as the cross product of tobacco (dichotomous/continuous) and coal (dichotomous/continuous) or type of coal (categorical) assessed. Stratified analyses by other types of solid fuel (smokeless coal, wood) were not substantial and the results are not presented here. All reported P-values for Table I were Wald chi-square for categorical variables and t-test for continuous variables; all P-values for Tables II-IV were Wald chi-squares. All analyses conducted using SAS version 9.22 (SAS Institute, Cary, NC, USA).

Results

Demographics of the 260 cases and 260 controls are presented in Table I. Cases tended to smoke more cigarettes than controls, although the difference was not significant (p-value>0.05). However, controls smoked more pipe tobacco than cases (p-value < 0.05).

History of coal mining jobs, familial history of lung cancer, history of non-malignant lung disease, and coal use were significantly different and generally appeared to be greater or more common in cases (all p-values< 0.05).

Odds ratios for coal and tobacco use are presented in Table II. Ever smoky coal use was associated with a 6.31 fold increased risk of lung cancer (95% CI: 2.85-13.94). Coal from Lai Bin and Long Tan were most strongly associated with lung cancer risk (OR: 14.99; 95% CI: 6.03-37.21). Ever smoking was positively, although not significantly, associated with lung cancer risk (OR: 1.21; 95% CI: 0.79-1.88).

Odds ratios for lung cancer risk and tobacco use stratified by coal type/source are presented in Table III. While cigarettes were weakly associated with lung cancer risk, when stratified by smoky coal used, ever smoking cigarettes was non-significantly associated with a 2.51 fold increased risk of lung cancer in men who never used smoky coal (95% CI: 0.40-15.67, data not shown). The association remained non-significant and was weaker in men who did use smoky coal (OR: 1.23; 95% CI: 0.78-1.94, data not shown). When stratified by coal type, an increased risk of lung cancer per cigarette per day was significantly elevated among those not using Lai Bin or Long Tan coal (per cigarette/day: OR: 1.07; 95% CI: 1.02-1.13) and elevated but not significant among men who never used coal. In contrast, cigarettes were not associated with lung cancer risk in Lai Bin/Long Tan coal users, and the risk was significantly different from non-Lai Bin/Long Tan coal users (P-interaction: 0.014) and non-smoky coal users (0.0079).

Odds ratios for lung cancer risk and cigarette use by coal usage are presented in Table IV. A significantly increased relative risk of lung cancer per cigarette per day (>0-3 tons: OR: 1.09; 95% CI: 1.03-1.17; >3 tons: OR: 0.99; 95% CI: 0.95-1.03) was observed in low coal users but not in the high users. Even at low levels of Lai Bin/Long Tan coal usage, cigarettes had no association with lung cancer risk (OR: 1.02; 95% CI: 0.91-1.14). Duration of smoking was not associated with lung cancer risk in any coal use groups (p-values > 0.05).

Results for water pipe smoking were inconsistently or inversely associated with lung cancer risk in the lowest coal use groups, but all interactions were not significant (p-interaction > 0.05) (Supplemental Table I).

Discussion

We found that the relative effect of smoking on lung cancer risk was stronger in men who used less smoky coal and less hazardous coal. Further, the effect of smoking on the relative risk of lung cancer became most apparent when measured by intensity, and the attenuation appeared even at low levels in Lai Bin/Long Tan coal users.

To the best of our knowledge, this is the first study to evaluate the strength of the association between tobacco smoking and lung cancer risk by the intensity and type of coal used. The modest effect of tobacco use on lung cancer risk, in particular pipe tobacco [1-5, 18], in this study was consistent with previous research conducted in this population. Lee et al.[6] noted a stronger association between lung cancer risk and cigarettes after chimney installation, which reduced exposure to smoky coal combustion exhaust. The positive association between lung cancer and tobacco use was significant, and the authors suggested that smoky coal exhaust inhalation may overwhelm the effect of tobacco. By extension, we noted attenuation of the cigarette-lung cancer risk association as intensity of coal use increased and Lai Bin or Long Tan coal were used. These results were most striking when assessed by intensity rather than duration (years of usage). This could be due to intensity metrics better approximating concurrent exposures than duration. Interestingly, the reduction effect is somewhat similar to a recent observation reported in a nested case-control study of lung cancer and diesel exhaust exposure in an occupational cohort of non-metal miners (employed underground in enclosed areas with high levels of diesel exhaust) in the United States[17]. We observed that water pipe smoking was weakly (or inversely in stratified analysis stratum) associated with lung cancer risk, which is consistent with previous epidemiological studies which reported stronger effects of cigarette smoking than of pipe smoking on lung cancer[19-21]. Previous studies in Xuanwei and other places of China as well as a meta-analysis[22] found a weak or null association for water pipe use with lung cancer risk. Given the small sample size of our study, we believe the inverse association observed in our study was due to chance.

One possible reason this study observed attenuation of tobacco's effect as the intensity of coal use increased could be if one or more constituents of coal reduce the activation or increase the detoxification of carcinogens in tobacco smoke. For example, exposure to high levels of PAH in smoky coal might compete for metabolic activation of PAHs in tobacco [15]. Additional research is needed to further explore potential mechanisms that might explain the observation we report here.

Alternatively, smoky coal exposure may increase mucus formation in the bronchus, improving tobacco smoke clearance or reducing the depth of inhalation. A similar mechanism was also suggested in a study where the effect of diesel exhaust on lung cancer risk in miners was attenuated when tobacco smoke and diesel exhaust exposure occurred together[17].

Another possible explanation is that the age of carcinogenic exposure to smoky coal, which begins at birth for any individuals born in Xuanwei, compared to tobacco smoking, which would not begin until later in life, would have a longer period of time to initiate and develop the carcinogenic process before smoking could have an impact.

The association between cigarette smoking and lung cancer becomes more apparent as indoor air quality improves. Improving household ventilation is a process that began in the late 1970's/early 1980's but is still an ongoing effort, so interventions to promote smoking prevention and cessation will become increasingly important as more pollution levels decrease in homes of developing populations, and in particular, China. China is the world's largest producer and consumer of tobacco with over 300 million people (28% of the population) who regularly smoke[23].Smoking-related diseases were estimated to cost the country $5.0 billion in 2000[24]. Even today, people continue to use coal and are exposed to high levels of household air pollution in China[10].

Xuanwei's location lent both strengths and limitations to this study. The population is very stable. Most subjects lived in only one or two residences over their lifetimes with few changes in fuels used for cooking and heating. Participation rates were very high (100% for cases and 97% for controls). Approximately 17% of cases had surrogate respondents (of which 27% spouse, 53% offspring, 7% parent, 13% other family member). The unawareness of a case's early life exposure may misclassify the exposure status and bias the results. However, exclusion of the cases with proxy interviews did not lead to a meaningful change in effect estimates. Histologic confirmation of cases was available for only 39% of cases; however, other potential competing diseases that may have been responsible for lung cancer symptoms were carefully considered by diagnosing physicians to minimize misdiagnoses. We adjusted for potential confounders previously identified in this population, and the results were similar. Information collected about coal and tobacco use was detailed and comprehensive. We characterized the coal and smoking exposures several ways (ever, intensity, duration) to minimize potential inaccuracies in the exposure metrics. However, we cannot rule out the possibility of chance findings, and further studies are needed to confirm our findings.

In summary, our study found an increase in the observed relative risk of cigarette smoking on lung cancer risk in Xuanwei men who used less toxic coal and less total coal compared to those who used more coal and more hazardous coal in a case-control study of men living in Xuanwei, China. To the extent that our findings are generalizable to other populations using coal for cooking and home heating, our findings suggest that the effect of smoking on risk of lung cancer may increase as household air pollution decreases, and the health impact of cigarette smoking may become more pronounced over time, increasing the importance of tobacco cessation programs in combination with efforts to reduce indoor air pollution. Further research is needed to study the relationship between decreasing indoor air pollution, tobacco use, and tobacco-related disease in other populations.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Demographic characteristics of lung cancer cases and controls in Xuanwei, China

	Cases (n=260)		Controls (n=260)		
Characteristic	**n**	**%**	**n**	**%**	**P-value***
Ever Had Mining Job					
Yes	48	18.46%	24	9.2%	<0.0001
No	212	81.54%	236	90.8%	
Family History Lung					
Cancer					
Yes	22	8.46%	1	0.4%	<0.0001
No	238	91.54%	259	99.6%	
Literate					
Yes	136	52.31%	111	42.7%	0.025
No	123	47.31%	149	57.3%	
History of non-malignant Lun g Disease					
Yes	63	24.23%	11	4.23%	<0.0001
No	197	75.77%	249	95.77%	
Ever Used Smoky Coal					
Yes	249	95.77%	209	80.38%	<0.0001
No	11	4.23%	51	19.62%	
Ever Smoked					
Yes	234	88.85%	226	86.54%	0.64
No	26	11.15%	34	13.46%	
	Mean	**SD**	**Mean**	**SD**	**P-value***
Subject Age	53.17	12.48	52.64	12.57	0.62
Cigarettes Per Day	8.71	10.18	5.46	8.23	0.079
Pipe Per Day (34g)	13.79	12.78	18.84	13.78	<0.0001
Years of Smoking	30.21	15.48	27.75	16.26	0.079
Passive Smoke (Cigs/Day)	3.04	9.15	2.03	6.59	0.009
Annual Smoky Coal	3.8	2.35	3.45	2.51	0.077

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	Cases (n=260)		Controls (n=260)		
Characteristic	**n**	**%**	**n**	**%**	**P-value***
Smoky Coal Years	47.42	16.68	38.33	23.42	<0.0001

*P-values calculated by Wald chi-square test for categorical variables, t-test for continuous variables

Table 2

Smoky Coal Mine Source, Smoky Coal Use, Cigarette Smoking and Risk of Lung Cancer Among Males

	Cases	Controls	OR (95% CI)
Smoky Coal Use^			
Coal User (Ever/Never)			
Never	11	51	1.00 (reference)
Ever	249	209	**6.31 (2.85-13.94)**
Coal (Per Ton/Year)			1.08 (1.00-1.18)
Coal (Duration, Year)			**1.03 (1.02-1.05)**
Coal Mine Source^			
Never Used Smoky Coal	11	51	1.00 (reference)
Never Used Lai Bin/Long Tan Coal	70	146	**2.76 (1.11-6.83)**
Ever Used Lai Bin/Long Tan Coal	179	63	**14.99 (6.03-37.21)**
Cigarette Use#			
Cigarette Smoker (Ever/Never)			
Never	26	34	1.00 (reference)
Ever	234	226	1.21 (0.78-1.87)
Cigarette Smoke (Per Cig/Day)			1.02 (1.00-1.05)
Cigarette Smoke (Duration, Year)			1.01 (0.99-1.05)

^ OR per unit change; Adjusted for age, tobacco use, passive smoking, first-degree relative with lung cancer, literacy, ever had coal mining job

OR per unit change; Adjusted for age, total coal use, passive smoking, first-degree relative with lung cancer, literacy, ever had coal mining job

Table 3

Effect of Cigarette Smoking and Risk of Lung Cancer by Smoky Coal Mine Source[&]

	Cases		Controls		OR (95% CI)*	P-value	OR (95% CI)*	P-value
					Cigarettes/Day		Cigarette Duration (Years)	
Coal Mine Source	**Smoker**	**Non-Smoker**	**Smoker**	**Non-Smoker**				
Ever Used Smoky Coal (SC)	225	24	184	25	1.03 (1.00-1.05)	0.087	1.02 (0.99-1.04)	0.14
Lai Bin/Long Tan Only (LB/LT)	148	13	51	8	1.00 (0.96-1.05)	0.95	1.02 (0.99-1.06)	0.23
Mixed Lai Bin/Long Tan & Other Smoky Coal (MC)	15	3	3	1	-	-	-	-
Never Used Lai Bin/Long Tan Coal (No LB/LT)	62	8	130	16	**1.07 (1.02-1.13)**	**0.029**	1.03 (1.00-1.07)	0.071
Never Used Smoky Coal (No SC)	9	2	42	9	1.27 (0.77-2.09)	0.35	1.03 (0.98-1.08)	0.28
P-interaction (LB/LT; No LB/LT)						**0.014**		0.39
P-interaction (LB/LT; NSC)						**0.01**		0.17
P-interaction (SC; NSC)						**0.0079**		0.16
P-interaction (LB/LT; MC; No LB/LT; No SC)						0.074		0.61

[&]Results presented as continuous variables

*Adjusted for age, passive smoking, first-degree relative with lung cancer, literacy, ever had coal mining job, quantity of coal used

Table 4

Effects of Cigarette Smoking and Risk of Lung Cancer by Smoky Coal Usage and Source Among Males

Intensity of coal use and cigarette smoking&

	Cases		Controls		OR (95% CI)*	P-value	OR (95% CI)*	P-value
					Cigarettes/Day		Cigarette duration(Years)	
Coal tons/year	**Smoker**	**Non-Smoker**	**Smoker**	**Non-Smoker**				
Annual Smoky Coal Use								
>0-3 tons	97	8	51	13	**1.09 (1.03-1.17)**	**0.0064**	1.02 (0.99-1.06)	0.26
>3 tons	128	16	133	12	0.99 (0.95-1.03)	0.62	1.00 (0.98-1.03)	0.82
P-interaction						**0.0079**		0.23
Annual Smoky Coal Use (Lai Bin/Long Tan Only)^								
>0-3 tons	62	4	18	5	1.02 (0.91-1.14)	0.79	1.03 (0.96-1.12)	0.41
>3 tons	86	9	33	3	0.94 (0.97-1.03)	0.16	1.01 (0.96-1.05)	0.73
P-interaction						**0.049**		0.49
Annual Smoky Coal Use (Never Lai Bin/Long Tan)^								
>0-3 tons	28	2	32	5	1.11 (0.93-1.33)	0.23	1.03 (0.92-1.17)	0.58
>3 tons	34	6	98	11	1.01 (0.93-1.09)	0.79	0.99 (0.95-1.04)	0.8
P-interaction						**0.034**		0.62

Duration of coal use and cigarette smoking&

	Cases		Controls		OR (95% CI)*	P-value	OR (95% CI)*	P-value
					Cigarette duration (Years)		Cigarettes/Day	
Coal years	**Smoker**	**Non-Smoker**	**Smoker**	**Non-Smoker**				
Years of Smoky Coal Use								
>0-40 Years	54	9	50	13	1.02 (0.96-1.08)	0.57	0.99 (0.93-1.06)	0.74
>40 Years	171	15	134	12	1.01 (0.99-1.03)	0.36	**1.03 (1.00-1.07)**	**0.04**
P-interaction						0.92		**0.035**
Years of Smoky Coal Use (Lai Bin/Long Tan Only)^								
>0-40 Years	37	5	12	7	1.03 (0.92-1.16)	0.56	0.99 (0.86-1.15)	0.96
>40 Years	111	8	39	1	1.01 (0.96-1.06)	0.73	**1.01 (0.96-1.06)**	**0.82**
P-interaction						0.56		0.86

Intensity of coal use and cigarette smoking[&]

	Cases		Controls		OR (95% CI)*	P-value	OR (95% CI)*	P-value
Coal tons/year	**Smoker**	**Non-Smoker**	**Smoker**	**Non-Smoker**	**Cigarettes/Day**		**Cigarette duration(Years)**	
Years of Smoky Coal Use (Never Lai Bin/Long Tan)ˆ								
>0-40 Years	11	3	36	5	0.91 (0.75-1.12)	0.37	3.14 (0.0001-999)	0.99
>40 Years	51	5	94	11	1.02 (0.99-1.06)	0.18	1.08 (1.01-1.15)	**0.024**
P-interaction						0.53		0.94

*Adjusted for age, passive smoking, first-degree relative with lung cancer, literacy, ever had coal mining job

&Results presented as continuous variables

ˆExcludes any subjects that used smoky coal from regions other than listed