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Household coal use and lung cancer: systematic review and meta-analysis of case–control studies, with an emphasis on geographic variation

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Background Emissions from household coal combustion associated with cooking and heating are an important public health issue, particularly in China where hundreds of millions of people are exposed. Although coal emissions are a known human carcinogen, there is still uncertainty about the level of risk for lung and other cancers.

Methods We performed a meta-analysis on 25 case–control studies (10 142 cases and 13 416 controls) to summarize the association between household coal use and lung cancer risk, and to explore the effect modification of this association by geographical location.

Results Using random-effects models, household coal use was found to be associated with lung cancer risk among all studies throughout the world [odds ratio (OR) = 2.15; 95% confidence interval (CI) = 1.61–2.89, $N_{studies} = 25$], and particularly among those studies carried out in mainland China and Taiwan (OR = 2.27; 95% CI = 1.65–3.12, $N_{studies} = 20$). Stratification by regions of mainland China and Taiwan found a variation in effects across the regions, with south/southeastern (OR = 3.27; 95% CI = 1.27–8.42, $N_{studies} = 3$) and southwestern China (OR = 2.98; 95% CI = 1.18–7.53, $N_{studies} = 3$) experiencing the highest risk. The elevated risk associated with coal use throughout Asia was also observed when stratifying studies by gender, smoking status, sample size, design (population vs hospital case–control) and publication language. No significant publication bias was found ($p_{Begg's} = 0.15$).

Conclusions Our results provide evidence that although the carcinogenic effect of coal use varies by location, coals from many locations exhibit elevated lung cancer risks.

Keywords China, Taiwan, India, indoor air pollution, solid fuels, cooking, heating

Introduction

About half of the world's population is exposed to smoke attributed to household solid fuel use, and it is estimated that about 1.6 million deaths per year were associated with this preventable exposure in 2000.[1] Solid fuel consists of mainly coal and various forms of biomass, such as wood, crop residues and animal dung. Whereas biomass is the most frequently utilized household fuel throughout the developing world, coal is widely used in China and to a lesser extent in a few other countries such as India and South Africa. Although a few studies have explored lung cancer risk and household biomass use,[2–7] many studies have focused on the risk associated with household coal use.[5,6,8–30] The first Global Comparative Risk Assessment Project organized by the World Health Organization estimated that in 2000 about 200 million people used coal for household cooking in East Asia and 25 million in South Asia, leading to an excess 16 000 premature deaths from lung cancer.[31]

Indoor emissions from household combustion of coal, which are widely prevalent throughout China and are also present in other Asian countries, have been deemed carcinogenic to humans.[32] Recent evidence suggests that lung cancer risk associated with household coal use may vary up to 25-fold based on the geographical location of the mines, even within a relatively small area.[30] The extent to which this association varies by geographical location more widely, however, has not been extensively studied. Therefore, we conducted a systematic review of the studies that evaluated household coal use for heating and cooking and lung cancer risk to summarize this association and to explore the potential effect modification of coal use and lung cancer risk by geographical location.

Methods

Studies examining the association between lung cancer risk and household coal use were identified by searching both English and Chinese databases. Studies in English published through June 2009 were identified by searches of the PubMed and Science Citation Index databases using keywords related to indoor air pollution ('IAP' OR 'indoor air' OR 'pollution' OR 'pollutant' OR 'fuel' OR 'fuels' OR 'coal' OR 'coals' OR 'charcoal' OR 'charcoals' OR 'cake' OR 'cakes' OR 'briquette' OR 'briquettes' OR 'solid fuel' OR 'solid fuels' OR 'biomass' OR 'anthracite' OR 'bituminous' OR 'fossil fuel' OR 'fossil fuels' OR 'lignite' OR 'subbituminous' OR 'stove' OR 'stoves' OR 'chula' OR 'chulla' OR 'oven' OR 'ovens' OR 'smoke' OR 'smoky' OR 'heat*' OR 'cook*' OR 'light*' OR 'burn*') and words related to lung cancer [('lung' OR 'bronchus' OR 'bronchial' OR 'bronchogenic' OR 'pulmonary' OR 'lower respiratory tract' OR 'trachea') AND ('cancer' OR 'cancers' OR 'carcinoma' OR 'carcinomata' OR 'neoplasm' OR 'neoplasms' OR 'tumor' OR 'tumors' OR 'tumours' OR 'tumour' OR 'adenocarcinoma' OR 'adenocarcinomata' OR '*small-cell')]. Studies in Chinese published through June 2009 were identified by searches of the China National Knowledge Infrastructure and Science Periodical Database of China within the (i) Mathematics/Physics/Mechanics/Astronomy, (ii) Chemistry/Metallurgy/ Environment/Mine Industry, (iii) Architecture/Energy/Traffic/Electromechanics, (iv) Agriculture, (v) Medicine and Public Health, (vi) Literature/History/Philosophy, (vii) Politics/Military Affairs/Law, (viii) Education and Social Sciences, (ix) Electronic Technology and Information Science and (x) Economics and Management models using similar keywords associated with indoor air pollution and lung cancer.

Studies included in our analysis were selected based on the following inclusion criteria: (i) the study was a case–control design, (ii) the study population's coal use exposures were primarily derived from household cooking and/or heating and not from other forms of urban/outdoor air pollution or occupational exposures, (iii) the study provided an adjusted odds ratio (OR) and 95% confidence interval (CI) for the risk of household coal use, (iv) the study differentiated the risk associated with coal use from that of biomass fuels and (v) the results for the study population were not reported in another publication.

The initial keyword searches of the English and Chinese databases yielded 10 369 manuscripts. Upon review of the manuscripts' titles, 545 manuscripts in English and 101 manuscripts in Chinese were selected for abstract review. In total, 60 English and 69 Chinese manuscripts were reviewed in full, with 25 studies (16 in English and 9 in Chinese) meeting all of the inclusion criteria for this meta-analysis.[5,6,8–30]

Data related to study design, geographical location, population setting, case selection, control selection, exposure assessment method, the number of cases and controls and risk of lung cancer associated with coal use were extracted from each study. We classified each study's exposure assessment method by the questions used to measure exposure: qualitative (i.e. questions with yes/no responses, such as do you burn coal at home?) and quantitative (i.e. number of years of exposure or amount of coal use). Multiple risk estimates were extracted from studies stratifying their results by a high and a low exposure, which are summarized in Table 1. For each study, the point estimate of the coal use effect for the highest exposure category was selected for use in this analysis. The high exposure category includes a 'yes' response for qualitative questions and the highest exposure category for quantitative questions. We also performed a sensitivity analysis using the lowest exposure category point estimates for studies, when results for multiple exposure categories were available. Results were also stratified by fuel type used in the

Table 1 Characteristics of case–control studies included in lung cancer risk and household coal use meta-analysis

References	Local region	Study period	Population setting	Study design	Cases (n = 10 142)	Controls (n = 13 416)	Participation rate: Cases (%)	Participation rate: Controls (%)	Exposure assessment classifications: Exposed subjects	Exposure assessment classifications: Unexposed subjects[a]	Type of question assessing exposure[b]	Exposed controls (%)
Studies in Africa												
Sasco *et al.*[8]	Casablanca	1996–98	Urban	Hospital-based case–control	118	235	>90	>90	Used coal for cooking and heating	Did not use coal for cooking and heating	Qualitative	5.1
Studies in Europe												
Lissowska *et al.*[5]	Czech Republic, Hungary, Poland, Romania, Russia, Slovenia, United Kingdom	1998–2001	[c]	Population- and hospital-based case–control	2861	3118	94	93	Ever used coal and never used wood for cooking	Never used solid fuel for cooking or heating; used modern fuels	Qualitative	28.7
Studies in North America												
Wu *et al.*[9]	California	1981–82	Urban	Population-based case–control	220	220	81	72	Coal burned for heating or cooking in a stove or fireplace during majority of childhood and teenage years	Not explicitly stated	Quantitative	[c]
Studies in India												
Gupta *et al.*[10]	Chandigarh	1995–97	Urban and rural	Hospital-based case–control	265	525	[c]	[c]	Years of exposure to coal for cooking: 1–45 years; >45 years	No years of exposure to coal for cooking	Quantitative	19.2
Sapkota *et al.*[6]	Ahmedabad, Bhopal, Calcutta, Chennai	2001–04	[c]	Hospital-based case–control	793	718	[c]	[c]	Always used coal for cooking	Always used modern fuels for cooking	Qualitative	1.4
Studies in mainland China and Taiwan												
Wu-Williams *et al.*[11]	Shenyang, Harbin	1985–87	Urban	Population-based case–control	965	959	92	[c]	Years of coal stove use: 21–40 years; ⩾41 years	⩽20 years of coal stove use	Quantitative	76.3
Sun *et al.*[12]	Harbin	1985–87	Urban	Population-based case–control	418	398	87	[c]	Used smoky coal for fuel needs	Did not use smoky coal for fuel needs	Qualitative	[c]
Huang *et al.*[13]	Sichuan	1990–91	Urban and rural	Hospital-based case–control	135	135	[c]	[c]	Coal burning indoors	Did not burn coal indoors	Qualitative	33.3
Ger *et al.*[22]	Taiwan	1990–91	[c]	Population- and hospital-based case–control	131	524	92	[c]	Used coal for cooking	Did not use coal for cooking	Qualitative	11.1
Li *et al.*[14]	Nanjing	1986–92	Urban	Population-based case–control	161	161	[c]	[c]	Used coal stove to heat room in winter	Did not use coal stove to heat room in winter	Qualitative	[c]
Dai *et al.*[15]	Harbin	1992–93	Urban	Population-based case–control	120	120	[c]	[c]	Period of heating by coal: 1-24 years; 25-34 years	Not explicitly stated	Quantitative	[c]
Luo *et al.*[23]	Fuzhou	1990–91	Urban	Population-based case–control	102	306	82	[c]	Presence of indoor air pollution from coal burning	No indoor air pollution from coal burning	Qualitative	[c]

(continued)

Table 1 Continued

References	Local region	Study period	Population setting	Study design	Cases ($n = 10142$)	Controls ($n = 13416$)	Participation rate		Exposure assessment classifications		Type of question assessing exposure[b]	Exposed controls (%)
							Cases (%)	Controls (%)	Exposed subjects	Unexposed subjects[a]		
Lin *et al.*[16]	Harbin	1985–90	Urban	Population-based case–control	122	122	[c]	[c]	Used coal stove in bedroom	Used coal stove in room other than bedroom	Qualitative	7.4
Ko *et al.*[17]	Taiwan	1992–93	[c]	Hospital-based case–control	117	117	91	94	Cooked with coal or anthracite from 20 to 40 years old	Cooked with gas or did not cook from 20 to 40 years old	Quantitative	1.4
Hao *et al.*[18]	Beijing	1981–86	Rural	Population-based case–control	220	440	94	[c]	Indoor coal burning without chimney	Indoor coal burning with chimney	Qualitative	[c]
Huang *et al.*[19]	Nanning	1993–96	Urban	Hospital-based case–control	122	244	[c]	[c]	Coal burning indoors	Did not use coal	Qualitative	[c]
Wu *et al.*[20]	Guangzhou	1997	Urban	Population-based case–control	258	258	[c]	[c]	Household coal use 10 years ago	No household coal use 10 years ago	Qualitative	[c]
Lan *et al.*[21]	Xuanwei	1995–96	Rural	Population-based case–control	122	122	98	100	Used $\geqslant$130 tons smoky coal without ventilation throughout lifetime	Used <130 tons smoky coal use without ventilation throughout lifetime	Quantitative	41.0
Lee *et al.*[24]	Taiwan	1993–99	Urban and rural	Hospital-based case–control	527	805	92	91	Cooked with coal or anthracite	Cooked with gas or did not cook	Qualitative	26.4
Kleinerman *et al.*[25]	Gansu	1994–98	[c]	Population-based case–control	846	1740	95	90	Used coal most frequently in home of longest residence	Used biomass most frequently in home of longest residence	Qualitative	20.0
Sun *et al.*[29]	Harbin	1996–99	Urban	Population-based case–control	206	618	[c]	[c]	Used >46 kg/m^2 of coal	Did not use coal	Quantitative	[c]
Lu *et al.*[27]	Guangzhou	1998–2001	[c]	Population-based case–control	445	445	[c]	[c]	Used coal in household	Did not use coal in household	Qualitative	2.5
Liang *et al.*[26]	Nanjing	2001–02	Urban	Hospital-based case–control	152	152	[c]	[c]	High number of years of using coal	Low number of years using coal	Quantitative	[c]
Galeone *et al.*[28]	Harbin	1987–90	Urban and rural	Hospital-based case–control	218	436	[c]	[c]	Ever used coal for cooking and heating	Never used coal for cooking heating	Qualitative	88.3
Lan *et al.*[30]	Xuanwei	1985–90	Rural	Population-based case–control	498	498	100	97	Smoky coal was used for the longest time for heating and cooking	Wood or smokeless coal was used for the longest time for heating and cooking	Quantitative	77.1

[a]Modern fuels include gas, electric and kerosene.
[b]All studies assessed exposure using a questionnaire. The questions used were classified into qualitative (i.e. questions with yes/no responses, such as do you burn coal at home?) and quantitative (i.e. number of years of exposure or amount of coal use).
[c]Not provided in the associated references.

unexposed group. To assess the robustness of data extraction, three of the manuscripts in English and two in Chinese were randomly selected and extracted by a second person. There was 100% concordance between the two independent data extractions.

All statistical analyses were performed using STATA version 10.1 (College Station, TX, USA). The adjusted ORs and 95% CIs from each study were used to estimate summary ORs. All ORs were adjusted for potential confounders of lung cancer, which may have included smoking, age and socio-economic status, among others. Using random-effects models, summary ORs were calculated for the overall effect of lung cancer and coal use, as well as after stratification by geographical location, study design, population setting, smoking status and gender. Heterogeneity among studies was determined using the I^2 test for heterogeneity. Publication bias was assessed via funnel plots and the Begg's test.[33] The robustness of our findings was evaluated by sensitivity analyses comparing the summary ORs between publication languages, study size and study design. ArcGIS (Redlands, CA, USA) was used to generate the map of mainland China and Taiwan.

Results

Twenty-five studies met our inclusion criteria, contributing a total of 23 558 subjects.[5,6,8–30] Table 1 summarizes the geographical location, study period, population setting, participation rate, exposure assessment methods and study design for each study. Only five studies evaluated the association between lung cancer and household coal use outside mainland China and Taiwan.[5,6,8–10]

Household coal use was associated with an increased risk of lung cancer when evaluating all studies (OR = 2.15, 95% CI = 1.61–2.89, $N_{studies} = 25$); however, there was substantial heterogeneity in this estimate ($I^2 = 90.4\%$, $P_{heterogeneity} = 1.39 \times 10^{-39}$). The stratification of studies by geographical location found household coal use to be associated with lung cancer risk in mainland China and Taiwan, which explained only a very small portion of the heterogeneity ($I^2 = 90.4\%$, $P_{heterogeneity} = 6.46 \times 10^{-32}$) (Figure 1). Further stratification of studies into regions of mainland China and Taiwan explained a substantial portion of the heterogeneity ($I^2 = 46.3\%$, $P_{heterogeneity} = 0.08$) and indicated that risk associated with lung cancer attributed to household coal use for heating and cooking varies geographically (Figure 2). South/southeastern and southwestern China experienced the highest risk of lung cancer associated with coal use. Other regions of mainland China that experienced an increased risk were the north, northeast, east and northwest, as well as Taiwan. No heterogeneity was observed when comparing the south/southeastern and the southwestern studies ($P_{heterogeneity} = 0.89$) or when comparing the south/southeast and southwest to the other regions of China ($P_{heterogeneity} = 0.10$).

Among studies from mainland China and Taiwan, males and females tended to have increased risk (Table 2). When summarizing the studies by smoking status, coal use was also associated with lung cancer risk among non-smoking females (Table 2 and Supplementary Figure S1). Studies that utilized a quantitative questionnaire to assess coal use exposures had a higher risk than those that utilized a qualitative questionnaire to assess exposures. Those carried out in rural and urban settings both observed increased risks.

To assess the robustness of our finding that household coal use is associated with lung cancer risk in mainland China and Taiwan, we restricted our analysis to various study characteristics in sensitivity analyses. Results remained significant when restricting the analysis to studies published in English, studies published in Chinese, studies with greater than 800 subjects, studies with less than 800 subjects, population-based case–control studies and hospital-based case–control studies (Table 2). Further, results were similar when excluding studies that did not account for personal smoking by either adjustment, matching or restricting to only non-smokers (OR = 2.34, 95% CI = 1.64–3.33, $N_{studies} = 17$). Elevated effects were also observed when stratifying by the type of fuel used in the unexposed group (coal: OR = 1.91, 95% CI = 1.60–2.26, $N_{studies} = 12$; biomass: OR = 1.29, 95% CI = 1.03–1.61; $N_{studies} = 1$; non-solid fuels: OR = 1.98, 95% CI = 1.16–3.36, $N_{studies} = 2$). We also performed a sensitivity analysis using the lowest exposure category point estimates for studies, when results for multiple exposure categories were available, and found similar results (OR = 2.13; 95% CI = 1.58–2.86, $N_{studies} = 25$). Further, in subgroups of studies without heterogeneity ($I^2 = 0\%$), such as non-smoking females, studies published in Chinese and hospital-based case–control studies, the association between coal use and lung cancer remained (Table 2). Finally, the exclusion of studies from Xuanwei, China, yielded a similar association between household coal use and lung cancer risk in mainland China and Taiwan (OR = 2.11, 95% CI = 1.50–2.95, $N_{studies} = 18$). No significant publication bias was found among all studies ($p_{Begg's} = 0.15$).

Discussion

Since humans spend a majority of their time indoors, pollutants present in the indoor environments are likely to have an impact on our health. Throughout the developing world, women traditionally spend much of their day indoors using solid fuels for heating and cooking. Thus, indoor air pollution and its health implications are of particular concern in these settings. Our meta-analysis has summarized the risk of lung cancer associated with household coal burning

Author	Study period	Cases	Controls	OR (95% CI)
Africa				
Sasco *et al.*[8]	1996–98	118	235	0.74 (0.17–3.14)
Subtotal				0.74 (0.17–3.14)
Europe				
Lissowska *et al.*[5]	1998–2001	2861	3118	1.13 (0.94–1.38)
Subtotal				1.13 (0.94–1.38)
North America				
Wu *et al.*[9]	1981–82	220	220	2.30 (1.00–5.50)
Subtotal				2.30 (1.00–5.50)
India				
Gupta *et al.*[10]	1995–97	265	525	1.52 (0.33–6.98)
Sapkota *et al.*[6]	2001–04	793	718	3.76 (1.64–8.63)
Subtotal				3.02 (1.42–6.46)
Mainland China and Taiwan				
Wu-Williams *et al.*[11]	1985–87	965	959	1.30 (1.00–1.70)
Sun *et al.*[12]	1985–87	418	398	2.26 (1.53–3.33)
Huang *et al.*[13]	1990–91	135	135	1.59 (1.01–2.07)
Ger *et al.*[22]	1990–91	131	524	1.44 (0.44–4.69)
Li *et al.*[14]	1986–92	161	161	2.08 (0.85–5.08)
Dai *et al.*[15]	1992–93	120	120	4.70 (1.28–17.18)
Lin *et al.*[16]	1985–90	122	122	3.24 (1.05–9.94)
Luo *et al.*[23]	1990–91	102	306	6.00 (5.07–7.10)
Ko *et al.*[17]	1992–93	117	117	1.30 (0.30–5.80)
Hao *et al.*[18]	1981–86	220	440	1.99 (1.16–3.43)
Huang *et al.*[19]	1993–96	122	244	1.76 (1.27–2.42)
Wu *et al.*[20]	1997	258	258	1.58 (0.89–2.80)
Lan *et al.*[21]	1995–96	122	122	2.40 (1.30–4.40)
Lee *et al.*[24]	1993–99	527	805	2.10 (1.20–3.70)
Kleinerman *et al.*[25]	1994–98	832	1724	1.29 (1.03–1.61)
Sun *et al.*[29]	1996–99	206	618	2.22 (1.28–3.86)
Lu *et al.*[27]	1998–2001	445	445	3.44 (1.38–8.57)
Liang *et al.*[26]	2001–02	152	152	2.02 (1.20–3.39)
Galeone *et al.*[28]	1987–90	218	436	2.19 (1.08–4.46)
Lan *et al.*[30]	1985–90	498	498	7.40 (4.10–13.10)
Subtotal				2.27 (1.65–3.12)
Overall				2.15 (1.61–2.89)

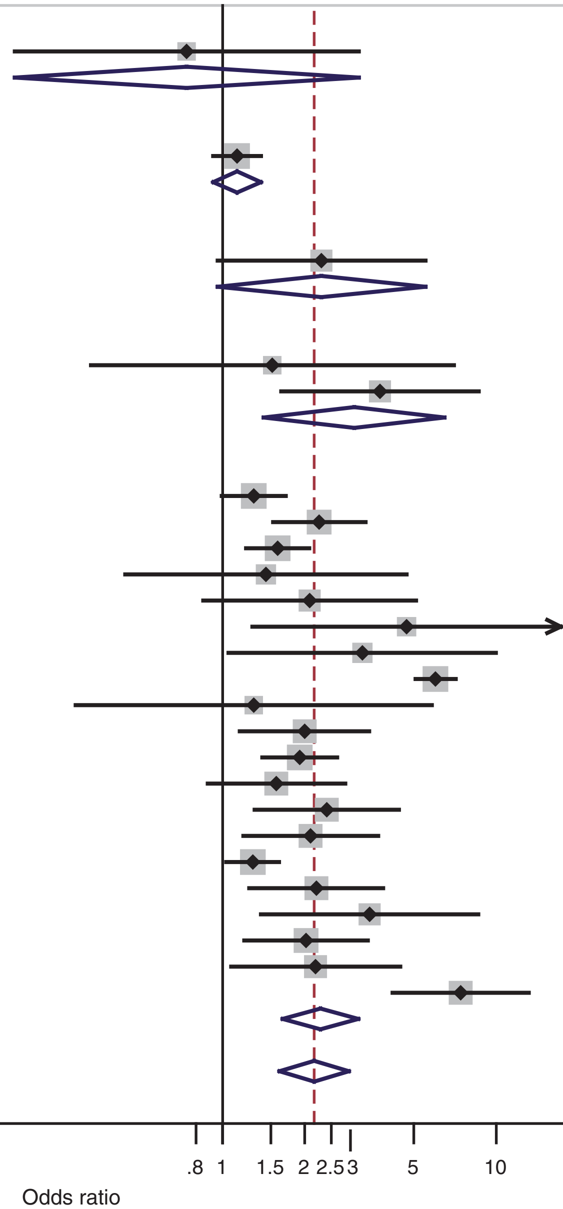

Figure 1 Summary risk estimates for lung cancer risk associated with household coal use for heating and cooking by geographical region. Square symbols represent each study's published adjusted ORs, with the size proportional to the number of cases and horizontal lines representing the 95% CIs; summary ORs and 95% CIs were calculated using random-effects models

for heating and cooking, and highlighted the importance of geographical variation when considering this risk factor. These observed risk estimates build off a previous systematic review and meta-analysis of case–control studies, which reported slightly lower risk estimates, but with overlapping CIs, for males and females.[31]

Our analyses found that coal use increased lung cancer risk, particularly throughout mainland China and Taiwan, with southwestern and south/southeastern China experencing the highest risks. Much of the literature from southwestern China has been focused on studies conducted in Xuanwei, a semi-mountainous county on a high plateau in northeastern Yunnan Province. Xuanwei experiences the highest lung cancer mortality rates in China for men and women, with a high portion of lung cancer attributable to coal burning.[34,35] The observed risk for south/southeastern China is mostly attributed to studies conducted in Guangzhou, an urban area with a population of over 2 million located in Guangdong Province. Similar to Xuanwei, Guangzhou experiences

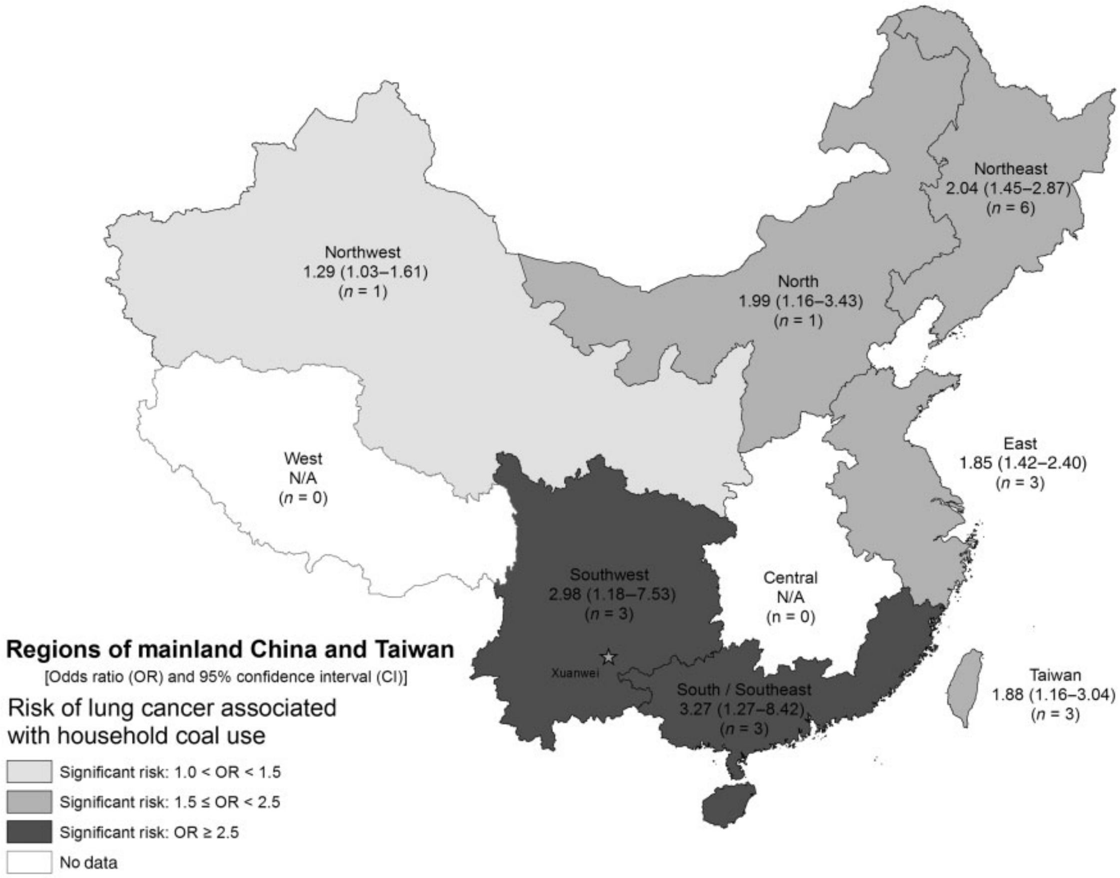

Figure 2 Summary risk estimates of lung cancer risk associated with household coal use for heating and cooking throughout mainland China and Taiwan. Random effects summary ORs and 95% CIs were calculated using each study's published adjusted ORs and 95% CIs

high levels of lung cancer in both males and females, even though >95% of the females are non-smokers.[36]

The observed geographical variation of lung cancer risk associated with coal use suggests that factors related to the carcinogenic potential of coal, and factors related to the levels of personal exposure to the combustion by-products from coal burning, may modify the risk. Coal carcinogenicity may be influenced by variation in the coal's composition. For example, various coals burned in the southern regions of China have been found to have increased polycyclic aromatic hydrocarbon (PAH), silica and arsenic content compared with coal used in other regions.[37–40] Other possible factors related to differing coal toxicities may include the volatility levels of benzene and formaldehyde found in the gas phase of the incomplete combustion products.[41–43] Through the process of coal formation, it is conceivable that coal from different seams throughout the world will vary in the proportion and composition of components,[44] leading some veins of coal to have higher carcinogenic potential than others.[45] In fact, lung cancer risk in Xuanwei varied up to 25-fold based on the location of the mine from which the coal was purchased.[30] Similarly, the risk of other non-malignant lung diseases has been found to vary by type of household fuel used for heating and cooking.[46] Therefore, research is needed to assess the levels of various carcinogenetic constituents in coal to determine which factor or factors are driving the risk of lung cancer associated with household coal use.

Levels of personal exposure may also influence cancer risk and will vary due to factors related to the intensity and duration of coal use, time spent indoors, the type of stove used and quality of ventilation. For example, spending greater than 7 waking hours indoors daily up to the age of 20 years old, as well as the number of years spent cooking, has been shown to influence the lung cancer risk associated with coal use in Xuanwei.[34,47] Further, changing from an unvented stove to a stove with a chimney or a portable stove was associated with a large and highly significant reduction in lung cancer for both men and women in Xuanwei.[34,47] In Guangzhou, living in a house with larger openings for ventilation decreased the risk of lung cancer association with household coal use.[48] Future studies of household coal use and other solid fuel sources should include at minimum qualitative, and ideally quantitative,

Table 2 Subgroup analyses of the lung cancer risk associated with household coal use for heating and cooking in mainland China and Taiwan

Subgroups within mainland China and Taiwan	Number of studies	Heterogeneity [I^2 (%); P-value]	OR (95% CI)
Gender			
Female	8	80.9; 5.3×10^{-6}	2.50 (1.56–4.00)
Male	3	82.4; 0.003	2.76 (1.44–5.27)
Non-smoking females	3	0.0; 0.433	2.93 (1.40–6.12)
Non-smoking males	0	Not applicable	Not applicable
Geographical setting			
Only studies carried out in an urban setting	9	92.8; 1.6×10^{-22}	2.35 (1.44–3.84)
Only studies carried out in a rural setting	3	83.4; 0.002	3.28 (1.46–7.39)
Type of questionnaire used to assess coal exposures[a]			
Only studies utilizing a qualitative question to assess coal exposure	13	92.5; 7.9×10^{-28}	2.16 (1.43–3.26)
Only studies utilizing a quantitative question to assess coal exposure	7	81.5; 1.4×10^{-5}	2.49 (1.47–4.20)
Publication language			
Only studies published in English	11	94.7; 3.9×10^{-35}	2.36 (1.42–3.94)
Only studies published in Chinese	9	0.0; 0.87	2.01 (1.69–2.40)
Sample size of study			
Only studies with greater than 800 subjects	6	87.5; 1.5×10^{-7}	2.27 (1.43–3.59)
Only studies with less than 800 subjects	14	88.5; 4.2×10^{-18}	2.24 (1.51–3.32)
Study design			
Only population-based case–control studies	13	93.2; 1.8×10^{-31}	2.57 (1.64–4.03)
Only hospital-based case–control studies	6	0.0; 0.89	1.75 (1.47–2.09)

[a]All studies assessed exposure using a questionnaire. The questions used were classified into qualitative (i.e. questions with yes/no responses, such as do you burn coal at home?) and quantitative (i.e. number of years of exposure or amount of coal use).

exposure assessment methodologies evaluating the amount of fuel used throughout subjects' lives and their doses to determine dose–response relationships.

Other factors that may explain the geographical variation, we observed, may include variation in prevalence of smoking or radon exposure or the background rates of lung cancer. Ecological comparisons of the patterns of these exposures, however, do not provide evidence that variations in these additional risk factors are likely to explain our findings to any substantial extent given that they do not systematically correlate with the risks we observed for coal use and lung cancer.[49–51]

Our analysis has multiple strengths. First, it has the largest sample size of any meta-analysis of household coal use and lung cancer risk, and is the first meta-analysis to evalaute this association globally. Through various sensitivity analyses based on publication language, study size and study design, we have evaluated the robustness of our observation that lung cancer is associated with coal use. As in a previous meta-analysis of this association,[52] we observered substantial heterogeneity in our summary ORs for coal use and lung cancer. However, our analysis was able to explain the majority of this heterogeneity through stratification by geographical location. Another strength of our analysis is that ~85% of the studies in mainland China and Taiwan accounted for smoking by either adjustment, matching or restricting to only non-smokers, and restriction to only these studies did not substantially change our results. Due to the small number of studies in Western countries, there was limited ability to evalaute the association between household coal use and lung cancer in North America and Europe. Further, few studies allowed for the separation of household coal use for cooking compared with heating.

In conclusion, our meta-analysis of 25 studies from four continents confirmed the association between coal use and lung cancer risk, especially in mainland China and Taiwan, even after excluding studies conducted in Xuanwei. Our results support the hypothesis that risk varies by geographical location and highlights the importance of future research. Further study should focus on determining and characterizing the varying carcinogenic potentials among coal subtypes and dwelling characteristics, which may explain the heterogeniety of risk of lung cancer associated with household coal use seen throughout the world. Our findings point to the need to reduce household coal exposures through the introduction of stove improvements or clean fuel and combustion technologies.

Supplementary Data

Supplementary Data are available at *IJE* online.

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KEY MESSAGES

- Hundreds of millions of people are exposed to smoke from household coal combustion in Asia.
- The risk of lung cancer associated with household coal use for heating and cooking varies by geographical region.
- Research is needed to determine factors contributing to the differing carcinogenic potential by coal subtype.
- Household coal exposures need to be reduced through the introduction of stove improvements or clean fuel and combustion technologies.

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