Airflow Obstruction and Use of Solid Fuels for Cooking or Heating
BOLD (Burden of Obstructive Lung Disease) Results

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Abstract

Rationale: Evidence supporting the association of chronic obstructive pulmonary disease or airflow obstruction with use of solid fuels is conflicting and inconsistent.

Objectives: To assess the association of airflow obstruction with self-reported use of solid fuels for cooking or heating.

Methods: We analyzed 18,554 adults from the BOLD (Burden of Obstructive Lung Disease) study, who had provided acceptable post-bronchodilator spirometry measurements, and information on use of solid fuels. The association of airflow obstruction with use of solid fuels for cooking or heating was assessed by sex, within each site, using regression analysis. Estimates were stratified by national income and meta-analyzed. We performed similar analyses for spirometric restriction, chronic cough, and chronic phlegm.

Measurements and Main Results: We found no association between airflow obstruction and use of solid fuels for cooking or heating (odds ratio [OR] for men, 1.20 [95% confidence interval (CI), 0.94–1.53]; OR for women, 0.88 [95% CI, 0.67–1.15]). This was true for low-/middle- and high-income sites. Among never-smokers, there was also no evidence of an association of airflow obstruction with use of solid fuels (OR for men, 1.00 [95% CI, 0.57–1.76]; OR for women, 1.00 [95% CI, 0.76–1.32]). Overall, we found no association of spirometric restriction, chronic cough, or chronic phlegm with the use of solid fuels. However, we found that chronic phlegm was more likely to be reported among female never-smokers and those who had been exposed for 20 years or longer.

Conclusions: Airflow obstruction assessed from post-bronchodilator spirometry was not associated with use of solid fuels for cooking or heating.

Keywords: chronic obstructive pulmonary disease; airflow obstruction; solid fuels (biomass); low-income countries

At a Glance Commentary

Scientific Knowledge on the Subject: Five systematic reviews, published between 2010 and 2014, reported that adults exposed to the burning of solid fuels were more likely to have chronic obstructive pulmonary disease (COPD) compared to those not exposed to this type of indoor pollution. However, these reviews suffered from some degree of publication bias and high heterogeneity across studies. Moreover, the diagnosis of COPD in many of the studies was not based on post-bronchodilator spirometry. More recent and larger studies failed to replicate the findings of the systematic reviews published so far. Overall, the evidence of an association between COPD and use of solid fuels for cooking or heating is conflicting and inconsistent.

What This Study Adds to the Field: Our findings are based on 18,554 adults from 25 sites who participated in the large population-based study BOLD (Burden of Obstructive Lung Disease) and had acceptable post-bronchodilator spirometry. We found that in adults, from low-/middle- and high-income countries, airflow obstruction was not associated with self-reported use of solid fuels for cooking or heating. This finding brings into question the extent to which high mortality rates attributed to COPD in low-income countries, where consumption of cigarettes is relatively low, are explained by use of solid fuels for cooking or heating.

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Chronic obstructive pulmonary disease (COPD) is the third leading cause of death worldwide and is particularly common in low-income countries (1). The most important single risk factor for COPD is cigarette smoking (2, 3). However, cigarette smoking is still uncommon in many low-income countries and >20% of people with this disease do not have a history of smoking (4, 5). Exposure to household air pollution from solid fuel burning for domestic purposes has been put forward to explain high COPD mortality, especially among nonsmokers and where the use of solid fuels for cooking or heating is widespread (5).

Five systematic reviews, published before 2015, reported an overall 1.9- to 2.8-fold increased risk for COPD in adults exposed, as compared with those not exposed, to solid fuel burning (6–10). In three of these reviews, the authors acknowledged evidence of publication bias toward the reporting of positive findings. These reviews also demonstrated very high levels of heterogeneity across studies, indicating either residual confounding or strong effect modification. A study performed on over 300,000 never-smokers from the China Kadoorie Biobank reported that airflow obstruction (a principal COPD feature) was positively associated with cooking with coal, but not with other types of fuel and only among women (11). Other studies have also reported differences between men and women in the effects of solid fuel burning both for cooking (12), and heating (13). An earlier report from the BOLD (Burden of Obstructive Lung Disease) study, mostly undertaken in high-income countries, also failed to show an association between airflow obstruction and use of solid fuel (14). Results from trials of solid fuel use reduction are so far inconclusive in relation to the effects on lung function (15, 16). Overall, the evidence supporting an association of COPD (or airflow obstruction) with use of solid fuels for cooking or heating is conflicting and inconsistent.

The main aim of the present analysis was to assess the association of airflow obstruction with self-reported use of open fires burning biomass, or coal, for cooking or heating in the large international, population-based BOLD study. In addition, we performed similar analyses for spirometric restriction, chronic cough, and chronic phlegm.

Methods

Participants

The BOLD study design and rationale have been described elsewhere (17). Representative samples of adults aged 40 years or older were recruited from sites in low-, middle-, and high-income countries. Information on respiratory symptoms and exposure to risk factors was collected through face-to-face interviews conducted by trained and certified staff in the participant's native language. Four sites did not use the questionnaire on use of open fires: Bergen (Norway); Hannover (Germany); Sydney (Australia); and Uppsala (Sweden). In the 29 remaining sites, 27,534 participants responded to the core questionnaire, of whom 23,250 had acceptable post-bronchodilator spirometry, and 20,746 also provided information on the use of open fires for cooking/heating. Sites where the prevalence of ever having used open fires for cooking/heating was either less than 0.5% (Mumbai [India]) or greater than 99.5% (Tirana [Albania]), Srinagar [India], and Adana [Turkey]) were excluded from the analysis. The present study population consisted of 18,554

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A complete list of BOLD collaborators may be found before the beginning of the References.

Author Contributions: A.S.B. and P.G.J.B. were engaged in the initial design of the study; A.F.S.A. and J.P. prepared and analyzed the data; A.F.S.A. and P.G.J.B. drafted the initial manuscript; all authors contributed to its development and approved the final version.

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Table 1. Characteristics of Participants from 25 sites of the BOLD (Burden of Obstructive Lung Disease) Study with Good Quality Spirometry and Data on Use of Solid Fuels for Cooking or Heating

	Annaba (Algeria)	Salzburg (Austria)	Sèmè-Kpodji (Benin)	Vancouver (BC, Canada)	Guangzhou (China)	London (UK)	Tartu (Estonia)	Reykjavik (Iceland)	Vadu (India)	Chui (Kyrgyztan)	Naryn (Kyrgyztan)	Blantyre (Malawi)	Penang (Malaysia)
n	890	1245	678	823	459	674	601	756	844	891	859	401	663
Males, %	49.9	46.3	49.3	47.2	52.0	46.3	38.9	51.2	59.8	41.5	47.7	54.1	49.2
Age, yr, mean (SD)	53.5 (10.9)	59.2 (12.1)	50.5 (9.6)	56.7 (12.6)	54.0 (10.6)	58.0 (12.4)	59.6 (12.2)	57.0 (9.5)	52.3 (10.0)	53.5 (10.2)	52.5 (9.9)	50.6 (9.4)	54.4 (10.4)
Height, cm, mean (SD)	164.4 (10.0)	168.9 (9.0)	165.7 (8.2)	167.9 (10.1)	160.3 (8.4)	167.9 (10.1)	168.0 (9.7)	172.7 (9.5)	158.8 (8.9)	162.8 (9.2)	161.9 (9.3)	162.5 (8.2)	158.6 (8.3)
Never-smokers, %	61.4	49.4	98.0	47.1	54.7	36.0	55.5	39.2	88.1	62.3	69.5	83.8	74.9
Pack-years, mean (SD)*	26.9 (20.5)	25.2 (23.2)	10.7 (8.8)	23.0 (25.0)	26.0 (17.8)	27.3 (30.1)	16.5 (15.1)	21.2 (29.0)	6.2 (8.7)	26.1 (21.3)	18.7 (15.5)	7.1 (10.5)	24.9 (21.7)
BMI, kg/m^2, mean (SD)	28.2 (5.6)	26.4 (4.3)	26.2 (5.4)	26.7 (5.1)	23.4 (3.3)	27.3 (5.3)	28.4 (5.3)	27.9 (5.0)	22.1 (3.9)	28.2 (5.9)	26.9 (5.1)	24.5 (5.2)	26.0 (4.6)
Education, yr†, mean (SD)	7.7 (5.4)	9.8 (2.2)	4.4 (4.9)	15.4 (3.4)	8.4 (3.9)	13.6 (3.6)	13.5 (3.8)	13.2 (4.4)	4.3 (4.3)	9.5 (1.6)	9.9 (1.5)	8.4 (4.4)	8.6 (3.7)
Exposure to dust in workplace, yr, mean (SD)	5.6 (10.3)	5.2 (11.7)	5.5 (10.1)	3.1 (7.3)	6.9 (11.5)	4.1 (9.7)	5.0 (10.1)	4.2 (9.6)	1.8 (5.5)	5.7 (10.9)	1.0 (5.0)	3.2 (7.2)	5.8 (10.7)
Use of solid fuels for cooking or heating, %	57.1	16.3	96.1	17.0	99.1	61.4	91.3	19.5	79.3	85.0	99.1	86.5	72.1
Duration of use of solid fuels, yr‡, mean (SD)	16.2 (10.5)	18.9 (13.5)	24.9 (10.8)	12.4 (9.5)	28.0 (10.9)	16.3 (10.4)	29.2 (18.8)	11.1 (6.0)	39.9 (15.7)	24.6 (15.2)	39.8 (16.5)	21.3 (13.0)	16.0 (8.6)
FEV_1, L, mean (SD)	2.7 (0.8)	2.9 (0.9)	2.3 (0.6)	3.0 (0.9)	2.4 (0.7)	2.7 (0.9)	2.9 (0.9)	3.0 (0.9)	2.2 (0.6)	2.7 (0.8)	2.8 (0.7)	2.5 (0.6)	2.2 (0.6)
FVC, L, mean (SD)	3.4 (0.9)	3.9 (1.0)	2.9 (0.7)	4.0 (1.2)	3.1 (0.8)	3.6 (1.1)	3.8 (1.1)	4.0 (1.0)	2.8 (0.7)	3.5 (0.9)	3.6 (0.9)	3.1 (0.7)	2.7 (0.7)
Airflow obstruction, %	6.4	17.3	7.3	13.3	7.7	17.6	6.2	11.3	6.1	12.5	7.8	6.9	3.4
Spirometric restriction, %	26.5	9.1	78.4	8.4	29.8	17.8	8.5	12.6	66.1	12.3	10.3	46.4	58.0
Chronic cough, %	3.0	5.9	2.3	10.9	5.7	14.8	6.8	11.6	1.9	15.2	9.9	2.4	4.5
Chronic phlegm, %	2.7	8.4	2.2	10.6	7.0	14.2	8.7	9.2	1.4	9.2	7.4	0.2	4.0

	Fes (Morocco)	Maastricht (the Netherlands)	Ile-Ife (Nigeria)	Manila (the Philippines)	Nampicuan and Talugtug (the Philippines)	Krakow (Poland)	Lisbon (Portugal)	Riyadh (Saudi Arabia)	Uitsig/Ravensmead (South Africa)	Colombo (Sri Lanka)	Sousse (Tunisia)	Lexington (KY)
n	767	587	884	885	719	518	711	700	840	991	661	507
Males, %	52.1	46.7	54.3	47.6	49.5	49.8	45.3	51.7	43.5	46.3	51.0	46.3
Age, yr, mean (SD)	54.2 (11.9)	58.5 (11.9)	53.1 (11.3)	52.8 (11.0)	54.2 (10.6)	56.1 (11.8)	58.5 (12.0)	50.3 (7.7)	53.4 (10.5)	53.5 (9.3)	51.9 (9.5)	57.0 (11.6)
Height, cm, mean (SD)	162.1 (9.1)	169.0 (9.8)	164.6 (7.9)	156.9 (8.5)	158.7 (8.7)	166.8 (8.6)	161.7 (10.0)	162.2 (8.9)	162.3 (9.0)	156.8 (9.3)	163.8 (9.4)	168.0 (10.0)
Never-smokers, %	69.8	37.6	86.5	45.2	45.3	39.7	57.3	76.4	30.3	77.5	57.1	40.8
Pack-years, mean (SD)*	21.8 (20.2)	23.2 (19.5)	5.9 (9.0)	19.8 (21.5)	23.7 (19.2)	26.3 (28.5)	31.2 (30.5)	23.8 (20.1)	17.0 (16.7)	10.4 (0.0)	30.7 (22.5)	41.5 (36.6)
BMI, kg/m^2, mean (SD)	27.5 (5.2)	27.5 (4.6)	25.0 (5.2)	24.4 (4.7)	21.6 (4.1)	27.8 (4.7)	27.9 (4.7)	31.3 (6.0)	27.5 (7.3)	24.5 (4.7)	28.8 (5.6)	30.6 (6.5)
Education, yr†, mean (SD)	4.2 (5.3)	14.9 (5.1)	9.4 (5.9)	9.4 (3.6)	7.8 (3.6)	10.4 (3.4)	8.5 (4.9)	9.4 (5.5)	7.8 (3.3)	9.0 (3.7)	8.2 (5.2)	12.8 (3.4)
Exposure to dust in workplace, yr, mean (SD)	8.5 (12.8)	3.3 (8.9)	5.2 (10.3)	7.2 (10.8)	6.1 (11.7)	10.3 (13.4)	10.6 (14.4)	2.7 (7.9)	6.9 (10.4)	6.3 (11.1)	10.0 (13.0)	8.2 (12.1)
Use of solid fuels for cooking or heating, %	49.0	25.0	66.7	41.3	98.5	95.2	54.3	38.5	47.1	57.9	45.3	70.6
Duration of use of solid fuels, yr‡, mean (SD)	18.6 (11.6)	11.7 (8.5)	17.4 (15.7)	12.3 (9.9)	37.7 (16.6)	36.1 (18.2)	17.2 (10.3)	21.0 (15.8)	17.5 (10.4)	33.1 (17.4)	19.6 (13.0)	16.7 (11.4)
FEV_1, L, mean (SD)	2.7 (0.7)	2.9 (0.9)	2.3 (0.6)	2.1 (0.6)	2.1 (0.7)	2.9 (0.9)	2.7 (0.9)	2.5 (0.7)	2.3 (0.7)	1.9 (0.5)	2.8 (0.8)	2.7 (0.9)
FVC, L, mean (SD)	3.4 (0.9)	3.8 (1.1)	2.9 (0.7)	2.6 (0.7)	2.7 (0.8)	3.8 (1.0)	3.4 (1.1)	3.0 (0.8)	3.0 (0.9)	2.3 (0.6)	3.5 (0.9)	3.5 (1.1)
Airflow obstruction, %	8.9	18.9	7.0	9.4	15.0	13.7	8.3	3.2	19.3	7.8	5.3	14.4
Spirometric restriction, %	19.4	10.2	71.5	62.6	56.7	10.1	10.7	52.9	46.8	84.1	26.2	26.3
Chronic cough, %	10.6	5.4	0.4	6.6	7.7	7.7	10.4	12.5	11.8	7.5	11.3	19.5
Chronic phlegm, %	7.3	3.2	0.4	14.6	10.3	7.7	11.9	13.0	14.3	11.5	16.3	16.8

Definition of abbreviation: BMI = body mass index.
*Among ever-smokers.
†Education, years of schooling completed.
‡Among those who use solid fuels for cooking or heating.

individuals from 25 sites (Table 1). All sites received approval from their local ethics committee, and participants provided written informed consent.

Use of Solid Fuels for Cooking or Heating

The use of solid fuels was defined based on whether the participant had used an open fire with charcoal, coal, coke, wood, crop residues, or dung as the primary means of cooking or heating the house or water for greater than 6 months in their lifetime. Levels of exposure (years of use and hours per day spent cooking on an open fire) were also assessed.

Lung Function and Respiratory Symptoms

Lung function was assessed by spirometry technicians who were certified before data collection, received regular feedback on quality, and were required to maintain a prespecified quality standard. FEV_1 and FVC were measured using the ndd EasyOne Spirometer (ndd Medizintechnik AG) before and 15 minutes after administration of salbutamol (200 μg) from a metered-dose inhaler through a spacer. Each spirogram was centrally reviewed and scored based on the American Thoracic Society and European Respiratory Society acceptability and reproducibility criteria (18). We defined: *1*) airflow obstruction as a post-bronchodilator FEV_1/FVC less than the lower limit of normal (LLN) (19), based on reference equations for white individuals from the third U.S. National Health and Nutrition Examination Survey (NHANES) (20); and *2*) spirometric restriction as a post-bronchodilator FVC less than LLN, based on the same reference population.

Participants were considered to have: *1*) chronic cough if they answered "yes" to both "Do you usually cough when you don't have a cold?" and "Do you cough on most days for as much as three months each year?"; and *2*) chronic phlegm if they answered "yes" to both "Do you usually bring up phlegm from your chest, or do you usually have phlegm in your chest that is difficult to bring up when you don't have a cold?" and "Do you bring up this phlegm on most days for as much as 3 months each year?"

Statistical Analysis

We assessed, by sex, the association of airflow obstruction, spirometric restriction, chronic cough, and chronic phlegm with use of open fires burning solid fuels for cooking/heating using logistic regression models, which were adjusted for age (yr), body mass index ($<$18.5, 18.5 to $<$24, 24 to $<$30, and $\geqslant$30 kg/m^2), pack-years of smoking, and cumulative exposure to dust in the workplace (yr). The association of each outcome with use of solid fuels was estimated for each site using probability weights to allow for the sampling design (21), and then combined in a random-effects meta-analysis stratified by gross national income (low-/middle- vs. high-income countries) (22). The level of heterogeneity was summarized using the I^2 statistic (23). We also regressed FEV_1/FVC (%) and FVC (L) as continuous variables against the same independent variables.

In sensitivity analyses, we: *1*) restricted the main analysis to never-smokers; and *2*) further examined the association of each outcome with use of solid fuels for cooking. These further analyses were stratified by fuel ("charcoal, coal, or coke" or "wood, crop residues, or dung"), use of solid fuels for less than 20 or 20 years or greater, by those usually spending greater than 1 h/d cooking, and by those with or without ventilation (the use of ventilation was assessed by asking whether the participant's stove or fire was vented to the outside [e.g., through chimney or window]); *3*) excluded participants with less than 10 years of use of solid fuels; and *4*) used the Global Lung Function Initiative (GLI) 2012 multiethnic equations to calculate the LLN (24). In addition, we assessed the association of airflow obstruction with duration of use of solid fuels (per 10 yr of use).

In an ecological analysis, we plotted the prevalence of each outcome against the proportion using solid fuels for cooking/heating after adjusting for the effects of age, body mass index, pack-years, and exposure to dust in the workplace.

All analyses were conducted using Stata/SE V.14.1 (StataCorp LP), and results considered significant at *P* less than 0.05. Some of the data from nine sites (six from high-income countries) have been published in an earlier report (14).

Results

The characteristics of the 18,554 participants included in this study are presented in Table 1. There were more females than males, and the mean age ranged from 50.3 to 59.6 years. Cumulative smoking history (i.e., pack-years) varied across sites, and most participants from low-/middle-income sites were never-smokers. The proportion of people who had used solid fuels for cooking/heating varied from 16.3% in Salzburg (Austria) to 99.1% in Guangzhou (China) and Naryn (Kyrgyzstan). The mean duration of use varied from 11.1 years in Reykjavik (Iceland) to 39.9 years in Vadu (India). The prevalence of the outcomes also varied: airflow obstruction from 3.2% in Riyadh (Saudi Arabia) to 19.3% in Uitsig/Ravensmead (South Africa); spirometric restriction from 8.4% in Vancouver (BC, Canada) to 84.1% in Colombo (Sri Lanka); chronic cough from 0.4% in Ile-Ife (Nigeria) to 19.5% in Lexington (KY); and chronic phlegm from 0.4% in Ile-Ife (Nigeria) to 16.8% in Lexington (KY).

Airflow Obstruction and Use of Solid Fuels

Participants who used solid fuels were not more likely to have airflow obstruction than those who did not use solid fuels (Table 2). The adjusted odds ratio (OR) and 95% confidence interval (CI) for the association between airflow obstruction and use of solid fuels was 1.20 (0.94–1.53) for men and 0.88 (0.67–1.15) for women. The estimates for this association were similar across low-/middle- and high-income sites. Among never-smokers, there was no evidence of an association of airflow obstruction with use of solid fuels (men: OR, 1.00; 95% CI, 0.57–1.76) (women: OR, 1.00; 95% CI, 0.76–1.32). The lack of a statistically significant association was also evident when examining it by cooking fuel, cumulative time of use for cooking, and the presence or absence of ventilation (Table 3).

There was no association between the FEV_1/FVC and use of solid fuels (*see* Table E1 in the online supplement). Exclusion of participants with fewer than 10 years of solid fuel use (Tables E2 and E3) and use of GLI2012 LLN equations did not change the results (Table 4). There was no significant exposure–response trend per 10 years of use (Table 5 and Table E4).

Spirometric Restriction and Use of Solid Fuels

There was no association between spirometric restriction and use of solid fuels among either men (OR, 0.89; 95% CI,

Table 2. Association of Airflow Obstruction, Spirometric Restriction, Chronic Cough, and Chronic Phlegm with Use of Solid Fuels for Cooking or Heating

	Men					Women				
		OR (95% CI)					OR (95% CI)			
	uCa:uNCa/nuCa:nuNCa	All Sites	LMIC	HIC	I^2 (%)	uCa:uNCa/nuCa:nuNCa	All Sites	LMIC	HIC	I^2 (%)
Overall										
Airflow obstruction	525:3,437/345:2,972	1.20 (0.94–1.53)	1.16 (0.90–1.51)	1.17 (0.73–1.86)	NS	439:4,527/380:3,273	0.88 (0.67–1.15)	0.81 (0.55–1.20)	0.94 (0.64–1.36)	44.5
Spirometric restriction	1,786:2,740/1,071:2,374	0.89 (0.75–1.06)	0.89 (0.76–1.05)	0.89 (0.58–1.37)	NS	2,327:3,015/1,117:2,646	1.03 (0.87–1.21)	1.02 (0.83–1.25)	1.04 (0.75–1.43)	NS
Chronic cough	328:3,301/233:3,038	0.94 (0.70–1.27)	1.06 (0.70–1.60)	0.80 (0.53–1.21)	NS	384:3,848/311:3,214	1.06 (0.79–1.42)	1.05 (0.68–1.63)	1.12 (0.79–1.60)	55.1
Chronic phlegm	409:3,121/278:2,980	1.23 (0.99–1.54)	1.19 (0.84–1.70)	1.37 (0.97–1.94)	NS	308:2,817/294:3,057	1.16 (0.94–1.42)	1.12 (0.93–1.36)	1.22 (0.76–1.97)	NS
Never-smokers										
Airflow obstruction	94:1,058/68:997	1.00 (0.57–1.76)	1.15 (0.62–2.14)	0.81 (0.26–2.48)	NS	252:3,236/155:2,127	1.00 (0.76–1.32)	1.11 (0.79–1.55)	0.75 (0.46–1.23)	NS
Spirometric restriction	860:965/449:899	0.72 (0.57–0.91)	0.62 (0.50–0.78)	1.20 (0.70–2.06)	NS	2,039:2,223/876:1,717	1.01 (0.84–1.21)	1.01 (0.82–1.23)	1.03 (0.63–1.69)	NS
Chronic cough	63:913/52:932	0.88 (0.55–1.40)	1.37 (0.69–2.72)	0.57 (0.29–1.09)	NS	223:2,598/139:1,860	1.33 (0.94–1.89)	1.36 (0.82–2.25)	1.30 (0.87–1.94)	50.7
Chronic phlegm	99:927/65:997	1.57 (0.90–2.74)	1.54 (0.68–3.51)	1.58 (0.69–3.62)	NS	204:2,189/155:2,015	1.28 (1.04–1.58)	1.29 (0.97–1.71)	1.42 (0.92–2.19)	NS

Definition of abbreviations: CI = confidence interval; HIC = high-income country; LMIC = low-/middle-income country; NS = non–statistically significant (i.e., $P > 0.05$) heterogeneity (I^2); nuCa = nonusers of solid fuel, cases; nuNCa = nonusers of solid fuel, noncases; OR = odds ratio; uCa = users of solid fuel, cases; uNCa = users of solid fuel, noncases.
Adjusted for age, height, body mass index, pack-years, and cumulative exposure to dusty jobs.

Table 3. Association of Airflow Obstruction with Use of Solid Fuels for Cooking in the BOLD (Burden of Obstructive Lung Disease) Study, Restricting the Analysis per Cooking Characteristics

	Men			Women		
Cooking fuel	**uCa:uNCa/nuCa:nuNCa**	**OR (95% CI)**	**I^2 (%)**	**uCa:uNCa/nuCa:nuNCa**	**OR (95% CI)**	**I^2 (%)**
Charcoal, coal, or coke*	154:848/312:2,642	1.19 (0.72–1.96)	50.9	196:1,751/329:2,238	1.12 (0.78–1.62)	NS
1–19 yr	75:442/307:2,605	1.15 (0.69–1.92)	43.3	72:569/328:2,198	1.15 (0.69–1.90)	47.3
20+ yr	79:379/238:1,858	1.00 (0.46–2.14)	54.7	122:1,099/329:223	1.29 (0.76–2.18)	NS
>1 h/d	4:17/22:144	1.10 (0.32–3.75)	NS	47:690/32:457	0.63 (0.25–1.62)	NS
with ventilation	3:15/22:144	0.82 (0.24–2.75)	NS	47:665/32:457	0.68 (0.26–1.81)	NS
without ventilation	1:2/17:119	6.69 (0.17–256)	NA	—	—	—
Wood, crop residues, or dung*	355:2,309/333:2,839	1.20 (0.89–1.60)	NS	265:2,900/373:3,096	0.96 (0.70–1.32)	44.2
1–19 yr	127:822/330:2,747	1.32 (0.94–1.84)	NS	86:910/361:2,972	1.00 (0.75–1.34)	NS
20+ yr	218:1,412/312:2,480	1.26 (0.85–1.87)	NS	177:1,817/300:2,491	1.18 (0.80–1.72)	NS
>1 h/d	20:137/27:265	1.10 (0.61–1.99)	NS	82:1,063/49:814	1.20 (0.48–3.02)	69.2
with ventilation	18:118/27:265	1.20 (0.68–2.10)	NS	79:996/49:814	1.26 (0.49–3.26)	67.2
without ventilation	2:4/5:111	13.4 (0.83–218)	NA	3:39/15:299	0.87 (0.15–5.08)	NS

Definition of abbreviations: CI = confidence interval; NA = not applicable (one site only); NS = non–statistically significant (i.e., $P > 0.05$) heterogeneity (I^2); nuCa = nonusers of solid fuel, cases; nuNCa = nonusers of solid fuel, noncases; OR = odds ratio; uCa = users of solid fuel, cases; uNCa = users of solid fuel, noncases.
Adjusted for age, height, body mass index, pack-years, and cumulative exposure to dusty jobs. Dashes indicate not enough observations for model to converge.
*Versus no use of solid fuels for cooking.

0.75–1.06) or women (OR, 1.03; 95% CI, 0.87–1.21) (Table 2). This pattern was similar across low-/middle- and high-income sites. Among male never-smokers, there was evidence of an inverse association between spirometric restriction and use solid fuels (OR, 0.72; 95% CI, 0.57–0.91). An association between spirometric restriction and use of solid fuels for cooking was still not present after examining the association by cooking fuel, cumulative time of use for cooking, and the presence of ventilation. Women who had ever used open fires burning charcoal, coal, or coke for 20 years or longer, more than 1 h/d, and without ventilation, were more likely to have restriction, whereas men who had ever used an open fire burning wood, crop residues, or dung were less likely to show restriction (Table 6).

There was no association between the FVC and use of solid fuels (Table E1). Exclusion of participants with greater than 6 months, but less than 10 years of solid fuel use (Tables E2 and E3), and use of the GLI2012 LLN equations did not change the results (Table 4).

Chronic Cough and Use of Solid Fuels

Chronic cough was not associated with use of solid fuels (men: OR, 0.98 [95% CI 0.71–1.34]; women: OR, 1.04 [95% CI, 0.77–1.41]; Table 2). No association between chronic cough and use of solid fuels was found in any of the sensitivity analyses, either restricting the analysis to never-smokers (Table 2) or by type of cooking fuel, cumulative time of exposure, or the presence of ventilation (Table 7).

Exclusion of participants with greater than 6 months, but less than 10 years of solid fuel use, did not change the results (Table E2).

Chronic Phlegm and Use of Solid Fuels

Overall, chronic phlegm was not associated with the use of solid fuels among either men (OR, 1.23; 95% CI, 0.99–1.54) or women (OR, 1.16; 95% CI, 0.93–1.45). However, among never-smokers, women who ever used solid fuels were 28% more likely to have chronic phlegm compared with women who never used solid fuels (OR, 1.28; 95% CI, 1.04–1.58; Table 2). Among men, the association of chronic phlegm with use of open fires was significant in those who used charcoal, coal, or coke for 20 years or greater and in those who used wood, crop residues, or dung and had been exposed for less than 20 years. Among women, the association was stronger in those who used either of the two groups of solid fuels for 20 years or greater (Table 8).

Exclusion of participants with fewer than 10 years of solid fuel use did not change the results (Table E2).

Ecological Analysis

At an aggregate level, there was no strong or significant correlation between the prevalence of airflow obstruction (men: r, −0.146; P, 0.5) (women: r, −0.353; P, 0.08), spirometric restriction (men: r, 0.171; P, 0.4) (women: r, 0.273; P, 0.2), chronic cough (men: r, −0.004; P, 1.0) (women: r, −0.326; P, 0.1), or chronic phlegm (men: r, −0.044; P, 0.8) (women: r, −0.386; P, 0.06), and use of solid fuels for cooking/heating (Figures 1 and 2). The weak correlation with spirometric restriction was strongly influenced by four sites in high-income countries (Iceland, the Netherlands, Canada, and Austria) with low levels of restriction, a finding typical of high-income countries, and low use of solid fuels.

Discussion

In this population-based study of adults, airflow obstruction was not associated with self-reported use of solid fuels for cooking/heating. The same was true for spirometric restriction and chronic cough. These findings were similar in low-/middle- and high-income sites, and are unlikely to be confounded by smoking, as they were also observed among never-smokers. The only significant association was for a 28% increase in risk of chronic phlegm among

Table 4. Association of Airflow Obstruction and Spirometric Restriction with Use of Solid Fuels for Cooking or Heating, Using Global Lung Function Initiative 2012 Equations for Different Ethnicities

	Men					Women				
		OR (95% CI)					OR (95% CI)			
	uCa:uNCa/nuCa:nuNCa	All Sites	LMIC	HIC	I^2	uCa:uNCa/nuCa:nuNCa	All Sites	LMIC	HIC	I^2
Airflow obstruction	605:3,631/373:3,040	1.14 (0.96–1.36)	1.13 (0.92–1.39)	1.15 (0.81–1.63)	NS	408:4,188/326:3,314	1.01 (0.77–1.33)	1.03 (0.72–1.47)	0.98 (0.63–1.54)	NS
Spirometric restriction	736:3,691/516:2,906	0.84 (0.70–1.00)	0.87 (0.72–1.06)	0.71 (0.48–1.05)	NS	926:4,181/522:3,236	0.93 (0.80–1.08)	0.94 (0.79–1.12)	0.92 (0.62–1.38)	NS

For definition of abbreviations, *see* Table 2.
Adjusted for age, height, body mass index, pack-years, and cumulative exposure to dusty jobs. White subjects: Annaba (Algeria), Krakow (Poland), Lexington (KY), Lisbon (Portugal), London (United Kingdom), Maastricht (the Netherlands), Reykjavik (Iceland), Salzburg (Austria), Sousse (Tunisia), Tartu (Estonia), and Vancouver (BC, Canada). Black subjects (and Indian subcontinent; although this subcontinent is not covered in Global Lung Function Initiative 2012, there is evidence showing that these groups are similar in terms of lung function [32]): Sèmè-Kpodji (Benin), Blantyre (Malawi), Uitsig/Ravensmead (South Africa), Ile-Ife (Nigeria), Vadu (India), and Colombo (Sri Lanka). Southeast Asian subjects: Guangzhou (China) and Penang (Malaysia). Other or mixed subjects: Fes (Morocco), Chui (Kyrgyztan), Naryn (Kyrgyztan), Manila (the Philippines), Nampicuan and Talugtug (the Philippines), and Riyadh (Saudi Arabia).

Table 5. Association of Airflow Obstruction with Duration of Use of Solid Fuels for Cooking or Heating

	Men					Women				
		OR (95% CI)					OR (95% CI)			
Airflow Obstruction	Ca:NCa	All Sites	LMIC	HIC	I^2 (%)	Ca:NCa	All Sites	LMIC	HIC	I^2 (%)
Overall										
Per 10 yr of use	961:7,425	1.07 (0.98–1.16)	1.08 (0.98–1.19)	1.05 (0.88–1.26)	56.2	905:8,913	1.00 (0.90–1.11)	0.98 (0.85–1.13)	1.04 (0.92–1.17)	64.8
Per 10 yr of use, excluding those with <10 yr of use	832:6,404	1.00 (0.99–1.16)	1.09 (0.99–1.19)	1.03 (0.86–1.24)	37.6	787:7,376	1.01 (0.91–1.11)	0.98 (0.85–1.13)	1.08 (0.96–1.20)	57.3
Never-smokers										
Per 10 yr of use	205:2,714	1.02 (0.87–1.21)	1.09 (0.97–1.22)	0.80 (0.43–1.49)	47.2	488:6,737	1.08 (0.99–1.18)	1.09 (0.98–1.22)	1.05 (0.88–1.26)	36.9
Per 10 yr of use, excluding those with <10 yr of use	172:2,154	1.00 (0.85–1.18)	1.08 (0.95–1.22)	0.82 (0.48–1.40)	44.2	405:5,384	1.08 (0.99–1.19)	1.08 (0.96–1.21)	1.13 (0.98–1.32)	NS

Definition of abbreviations: Ca = cases; CI = confidence interval; HIC = high-income country; LMIC = low-/middle-income country; NCa = noncases; NS = non–statistically significant (i.e., $P > 0.05$) heterogeneity (I^2); OR = odds ratio.
Adjusted for age, height, body mass index, pack-years, and cumulative exposure to dusty jobs.

Table 6. Association of Spirometric Restriction with Use of Solid Fuels for Cooking in the BOLD (Burden of Obstructive Lung Disease) Study, Restricting the Analysis per Cooking Characteristics

Cooking Fuel	Men			Women		
	uCa:uNCa/nuCa:nuNCa	OR (95% CI)	I^2 (%)	uCa:uNCa/nuCa:nuNCa	OR (95% CI)	I^2 (%)
Charcoal, coal, or coke*	444:831/882:2,122	0.83 (0.53–1.22)	54.0	715:1,184/888:2,522	1.03 (0.75–1.43)	49.9
1–19 yr	231:373/775:1,926	0.81 (0.54–1.22)	44.7	285:479/888:2,510	1.09 (0.80–1.48)	NS
20+ yr	210:415/803:1,646	0.82 (0.53–1.26)	NS	428:678/858:2,281	1.14 (0.69–1.90)	63.7
>1 h/d	22:22/271:184	0.66 (0.18–2.52)	NS	253:235/587:748	0.92 (0.50–1.72)	62.5
with ventilation	20:18/271:184	0.70 (0.23–2.13)	NS	224:228/587:748	0.82 (0.44–1.54)	59.8
without ventilation	—	—	—	17:7/186:295	3.15 (1.19–8.29)	NS
Wood, crop residues, or dung*	1,390:1,631/1,070:2,367	0.93 (0.79–1.10)	NS	1,784:1,697/1,117:2,642	1.06 (0.88–1.28)	NS
1–19 yr	512:657/1,064:2,343	0.88 (0.73–1.07)	NS	599:656/1,106:2,631	0.97 (0.74–1.28)	39.6
20+ yr	857:948/1,014:2,077	0.94 (0.73–1.22)	NS	1,164:1,014/1,064:2,204	1.07 (0.81–1.40)	NS
>1 h/d	107:59/272:194	0.61 (0.33–1.11)	NS	508:386/587:748	0.88 (0.57–1.35)	51.9
with ventilation	96:45/272:194	0.66 (0.43–1.00)	NS	451:353/587:748	0.91 (0.56–1.48)	57.1
without ventilation	10:12/209:49	0.16 (0.04–0.60)	NS	52:32/511:548	0.64 (0.31–1.32)	NS

Definition of abbreviations: CI = confidence interval; NS = non–statistically significant (i.e., $P > 0.05$) heterogeneity (I^2); nuCa = nonusers of solid fuel, cases; nuNCa = nonusers of solid fuel, noncases; OR = odds ratio; uCa = users of solid fuel, cases; uNCa = users of solid fuel, noncases.
Adjusted for age, height, body mass index, pack-years, and cumulative exposure to dusty jobs. Dashes indicate not enough observations for model to converge.
*Versus no use of solid fuels for cooking.

women who had never smoked, but had used solid fuels for cooking/heating. The findings were similar, but not significant, for men and for all participants regardless of smoking status.

The strengths of this study are: *1*) its large sample size and the inclusion of many sites; *2*) the use of a standardized protocol for spirometry and questionnaires for collecting data on risk factors across sites; *3*) the use of post-bronchodilator spirometric measurements; and *4*) the central quality control of all the spirometry and rigorous training of all study staff.

Nevertheless, this study also has limitations. As this is a cross-sectional study, we are unable to address temporality and draw firm conclusions in terms of causation. A longitudinal study showing no greater rate of lung function decline in the exposed group would be less open to confounding, and a negative randomized trial would be even stronger evidence. The information on solid fuel use was self-reported, and this may have led to exposure misclassification. Even nondifferential (unbiased) misclassification of the exposure will tend to reduce the estimate of the association between the exposure and the outcome. It may also be argued that the reporting of solid fuel use

Table 7. Association of Chronic Cough with Use of Solid Fuels for Cooking in the BOLD (Burden of Obstructive Lung Disease) Study, Restricting the Analysis per Cooking Characteristics

Cooking Fuel	Men			Women		
	uCa:uNCa/nuCa:nuNCa	OR (95% CI)	I^2 (%)	uCa:uNCa/nuCa:nuNCa	OR (95% CI)	I^2 (%)
Charcoal, coal, or coke*	91:798/174:2,151	0.95 (0.62–1.47)	NS	155:1,168/303:2,837	1.30 (0.87–1.96)	40.9
1–19 yr	44:380/171:2,082	0.88 (0.48–1.60)	NS	66:433/303:2,820	1.49 (0.90–2.49)	44.4
20+ yr	45:348/86:1,025	1.15 (0.42–3.11)	58.8	89:697/248:2,141	1.29 (0.57–2.91)	72.1
>1 h/d	2:19/16:150	1.24 (0.11–14.1)	NS	55:502/65:533	0.84 (0.16–4.32)	84.5
with ventilation	1:4/6:24	3.76 (0.63–22.4)	NA	52:485/34:367	0.91 (0.14–6.12)	88.8
without ventilation	1:2/10:126	3.04 (0.22–41.9)	NA	3:7/39:216	6.05 (0.12–300)	81.7
Wood, crop residues or dung*	210:2,108/168:2,472	1.21 (0.80–1.85)	55.7	251:2,668/290:3,071	1.17 (0.78–1.75)	66.3
1–19 yr	98:844/150:2,156	1.51 (0.83–2.72)	58.3	87:922/288:3,007	1.15 (0.78–1.68)	NS
20+ yr	107:1,121/153:2,188	1.14 (0.70–1.85)	47.6	164:1,551/215:1,880	1.47 (0.82–2.64)	70.8
>1 h/d	5:98/21:284	1.20 (0.11–13.0)	83.2	82:831/84:778	1.32 (0.44–3.99)	82.8
with ventilation	5:83/21:284	1.47 (0.12–17.8)	81.2	74:778/53:612	1.32 (0.36–4.75)	84.7
without ventilation	—	—	—	8:39/56:463	2.77 (0.57–13.6)	67.7

For definition of abbreviations *see* Table 3.
Adjusted for age, height, body mass index, pack-years, and cumulative exposure to dusty jobs. Dashes indicate not enough observations for model to converge.
*Versus no use of solid fuels for cooking.

Table 8. Association of Chronic Phlegm with Use of Solid Fuels for Cooking in the BOLD (Burden of Obstructive Lung Disease) Study, Restricting the Analysis per Cooking Characteristics

	Men			Women		
Cooking Fuel	**uCa:uNCa/nuCa:nuNCa**	**OR (95% CI)**	**I^2 (%)**	**uCa:uNCa/nuCa:nuNCa**	**OR (95% CI)**	**I^2 (%)**
Charcoal, coal, or coke*	108:764/226:2,236	1.28 (0.86–1.92)	NS	102:668/268:2,713	1.73 (1.22–2.44)	NS
1–19 yr	53:385/225:2,187	1.19 (0.68–2.06)	NS	49:275/244:2,197	1.78 (0.81–3.95)	75.3
20+ yr	54:327/123:1,079	1.74 (1.09–2.78)	NS	53:307/268:2,713	2.36 (1.47–3.77)	NS
>1 h/d	6:15/26:140	0.89 (0.15–5.36)	NS	25:177/75:743	1.91 (0.79–4.61)	NS
with ventilation	4:14/26:140	0.72 (0.20–2.55)	NS	20:162/47:574	2.02 (0.57–7.11)	72.0
without ventilation	2:1/20:116	11.3 (0.70–182)	NA	5:7/49:361	8.18 (0.97–69.3)	NS
Wood, crop residues or dung*	267:2,040/248:2,514	1.40 (1.03–1.89)	NS	201:1,747/294:3,057	1.41 (0.98–2.03)	62.7
1–19 yr	121:807/214:2,082	1.62 (1.04–2.51)	NS	90:810/284:2,847	1.17 (0.67–2.05)	67.8
20+ yr	142:1,149/205:2,050	1.31 (0.79–2.15)	53.0	110:874/260:2,552	2.09 (1.31–3.34)	53.8
>1 h/d	13:90/32:273	2.36 (0.12–47.8)	87.3	53:504/76:808	1.76 (0.87–3.60)	NS
with ventilation	11:77/32:273	1.92 (0.15–24.4)	82.8	44:449/48:639	1.74 (0.91–3.34)	NS
without ventilation	1:13/20:116	0.41 (0.04–3.98)	NA	9:38/59:492	2.92 (0.36–23.8)	79.9

For definition of abbreviations *see* Table 3.
Adjusted for age, height, body mass index, pack-years, and cumulative exposure to dusty jobs.
*Versus no use of solid fuels for cooking.

differs between low-/middle- and high-income countries. This is most likely to have influenced the ecological analyses, but is unlikely to have had much influence on the other analyses, as there was little evidence of heterogeneity in the results from different sites.

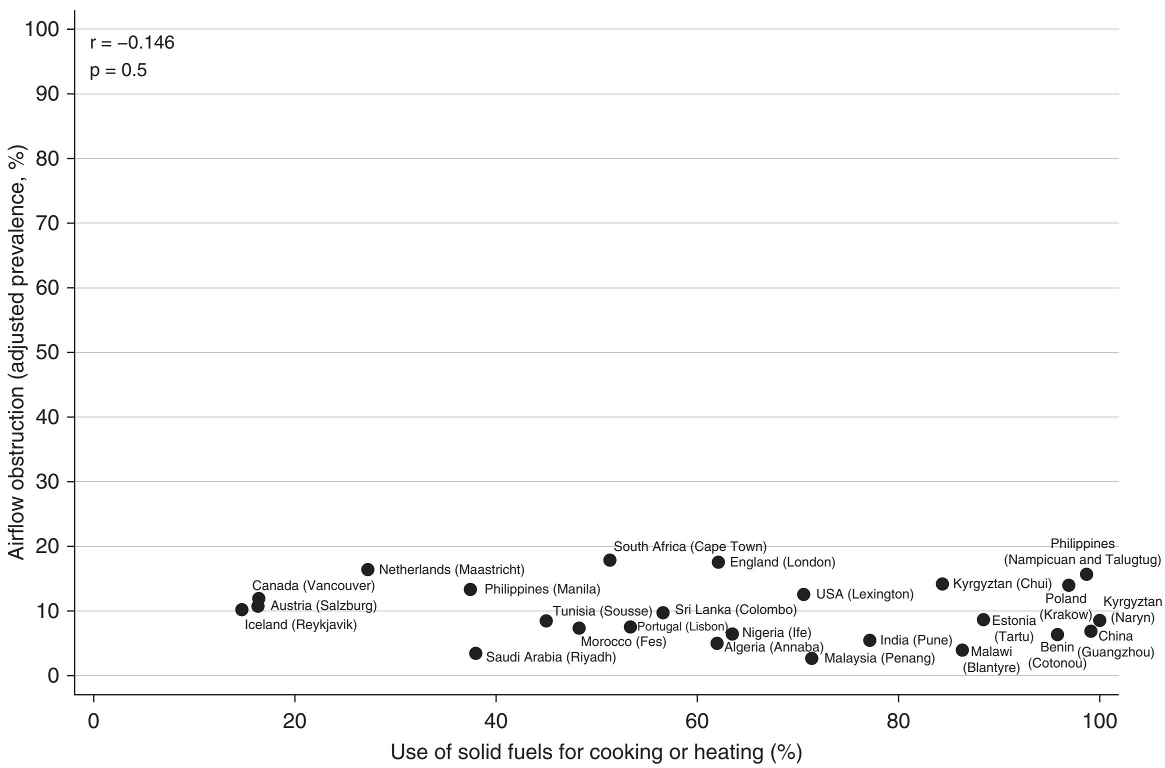
Assessment of lifetime exposure to open fires burning solid fuels was based on participants' recall. Although direct measurement of the concentrations of pollutants at an individual level would provide more precise assessments of current levels of exposure, these are less relevant to the study of chronic conditions that develop over many years, and all studies of chronic long-term effects have relied on a history of fuel use. We did not find an association between solid fuel use and airflow obstruction among people who had used this type of fuel for 10 years or greater, nor between increasing duration of use and any of the outcomes. Further restricting analyses to those who had been exposed for at least 20 years, for greater than 1 h/d, and with no ventilation did not change these conclusions. However, we had limited power to assess the effect of ventilation.

A frequent explanation that is given for negative findings in relation to indoor air pollution and lung function is that the exposure has been mismeasured and that regression-dilution bias may have led to underestimation of the risks. This is unlikely to explain the difference between our results and the results of the earlier meta-analyses (6–10). First, the assessments that we have made are not significantly worse than the measures that have been used in the past to support an association, but have been better standardized. Second, our conclusion is supported by the ecological analysis, which shows no significant association between the prevalence of the different outcomes and the prevalence of solid fuel use. As the exposure in this analysis is a summary of all the individual exposure measures in the sample, it is less prone to random error. Finally, the random error in answering simple questions on lifetime use of solid fuel is likely to be less marked than the random sampling error implicit in estimating levels of exposure over a lifetime from very short-term recent measurements. This may partly explain why associations reported from studies that have used an exposure history have not been replicated with measured exposures of air pollution (25).

Ecological data have been used in the past to argue for the potential importance of exposure to solid fuel burning in explaining the global distribution of mortality from COPD, but we have failed to show any clear association between the prevalence of spirometric measurements and the prevalence of use of solid fuel. In the absence of such an association, it is unlikely that a policy implemented at an area level to reduce exposure would have any marked effect on prevalence. We found no convincing evidence that the prevalence of airflow obstruction or any other abnormality was associated with the use of solid fuel after adjusting for the individual effects of smoking and other confounders. Although ecological analyses have their weaknesses, these are different from analyses based on individuals. The lack of association at both levels supports the negative finding.

Use of the NHANES reference equations for white subjects in our spirometry measurements may be thought to overstate lung function abnormality in some study sites, but is unlikely to affect these analyses. Reference equations do not define illness, but an arbitrary level of lung function (defined here as the upper bound for the lowest 5% of the "normal"—asymptomatic, nonsmoking—population). It is largely immaterial whether the definition uses the lower 1, 5, or 50%, and, as each site is analyzed separately in our analysis, the association with fuel use within each site will not be greatly affected by the choice of the cut point. To check this assumption, we reran our main results using the GLI2012 multiethnic reference equations and using the continuous outcome measures of FEV_1/FVC and FVC, which are not dependent on any reference equation. None of these analyses showed a significant change in the conclusions.

A



B

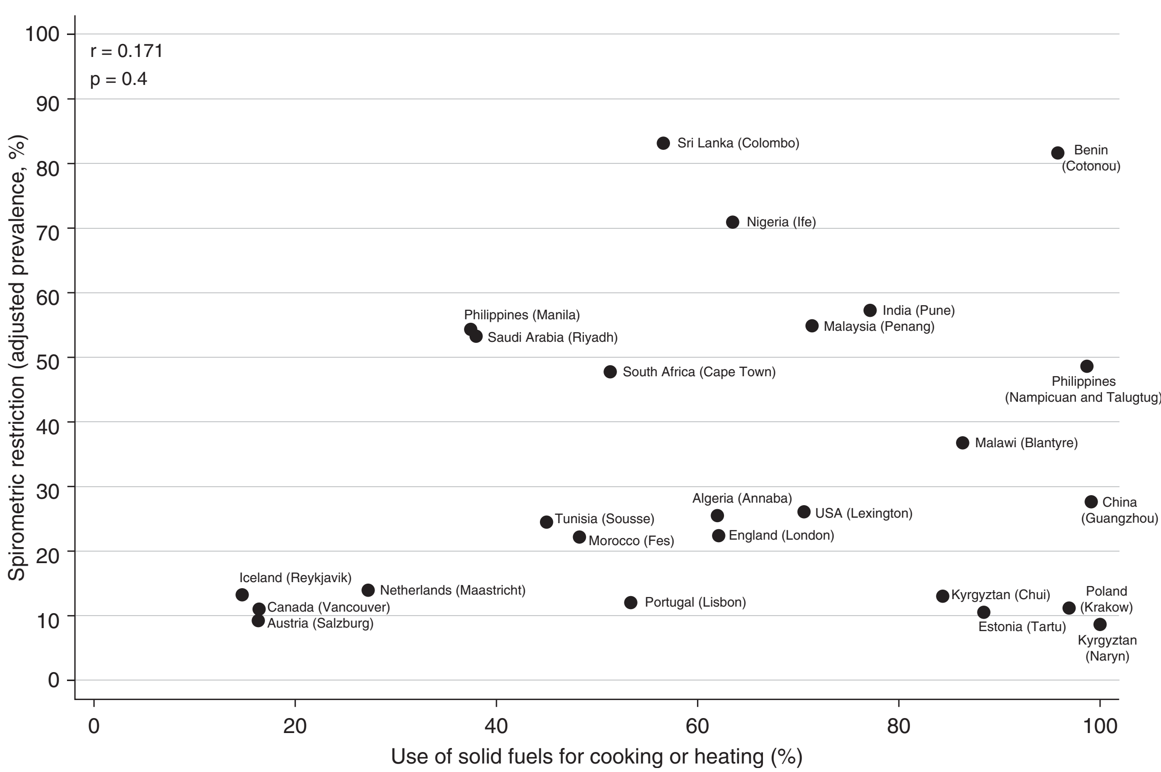
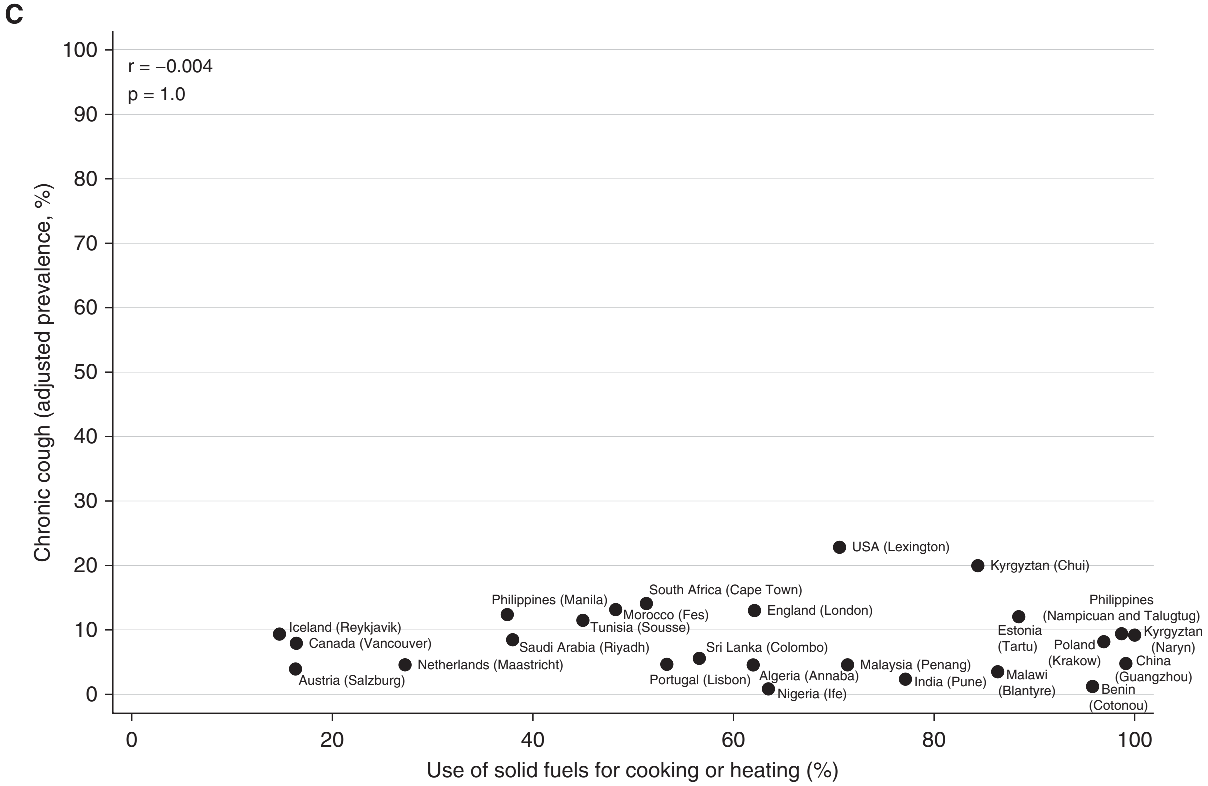


Figure 1. Correlation of airflow obstruction (*A*), spirometric restriction (*B*), chronic cough (*C*), and chronic phlegm (*D*) with use of solid fuels for cooking or heating in men in the BOLD (Burden of Obstructive Lung Disease) study.



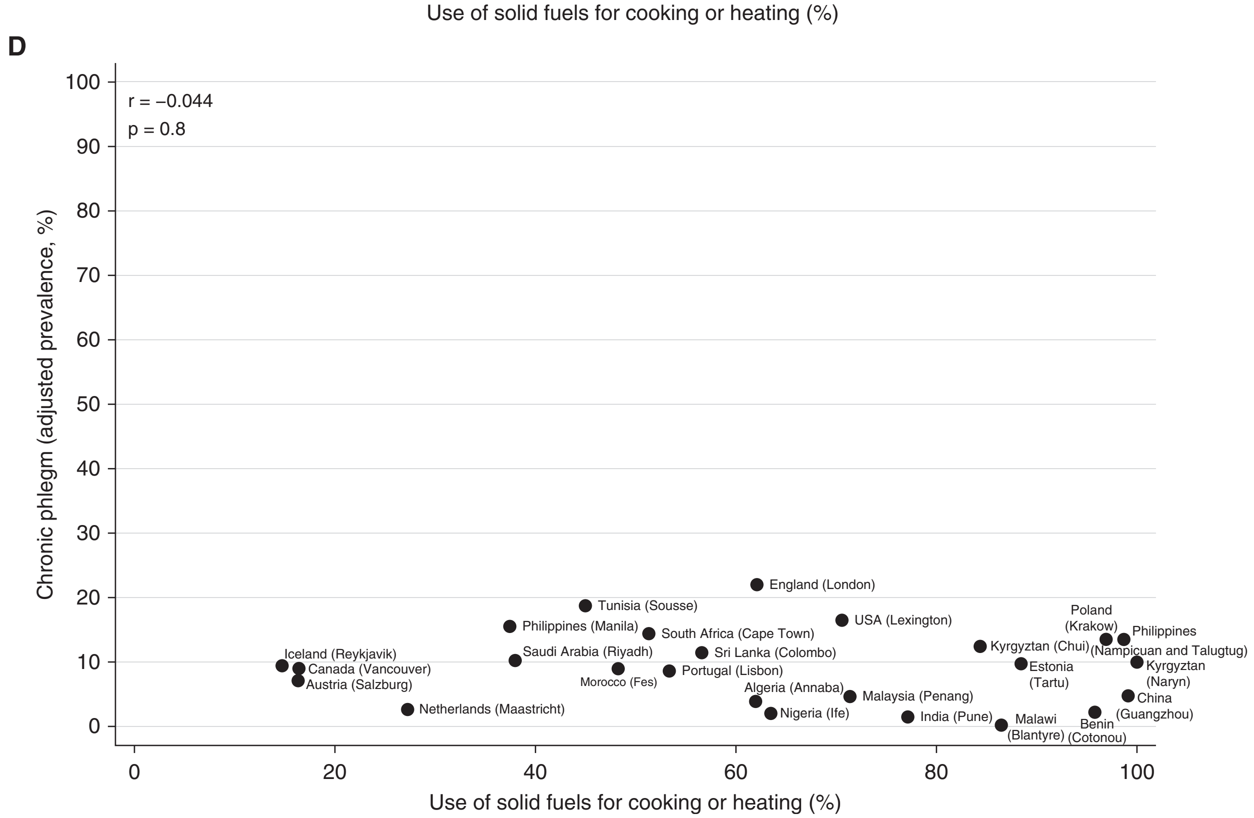


Figure 1. (Continued).

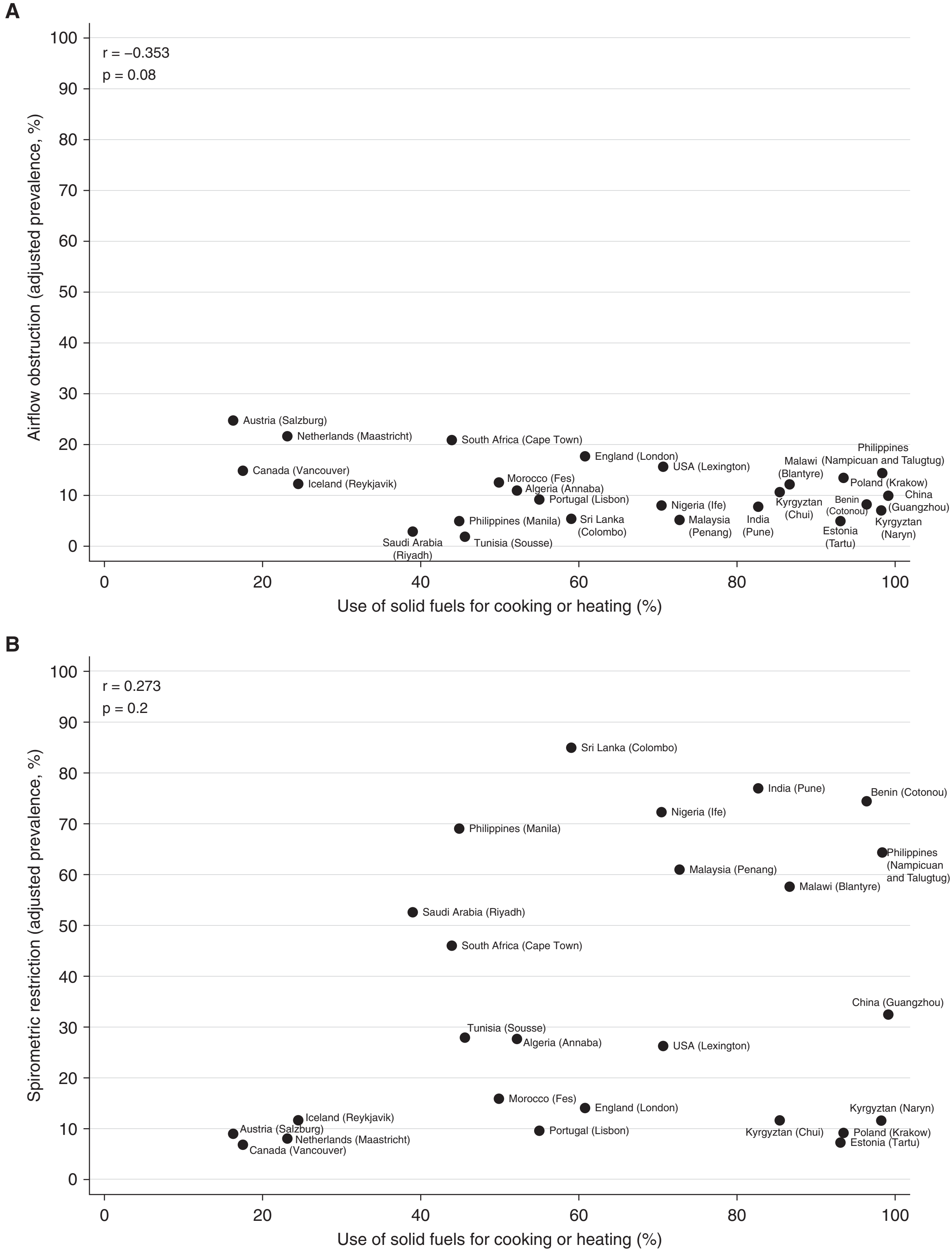


Figure 2. Correlation of airflow obstruction (*A*), spirometric restriction (*B*), chronic cough (*C*), and chronic phlegm (*D*) with use of solid fuels for cooking or heating in women in the BOLD (Burden of Obstructive Lung Disease) study.

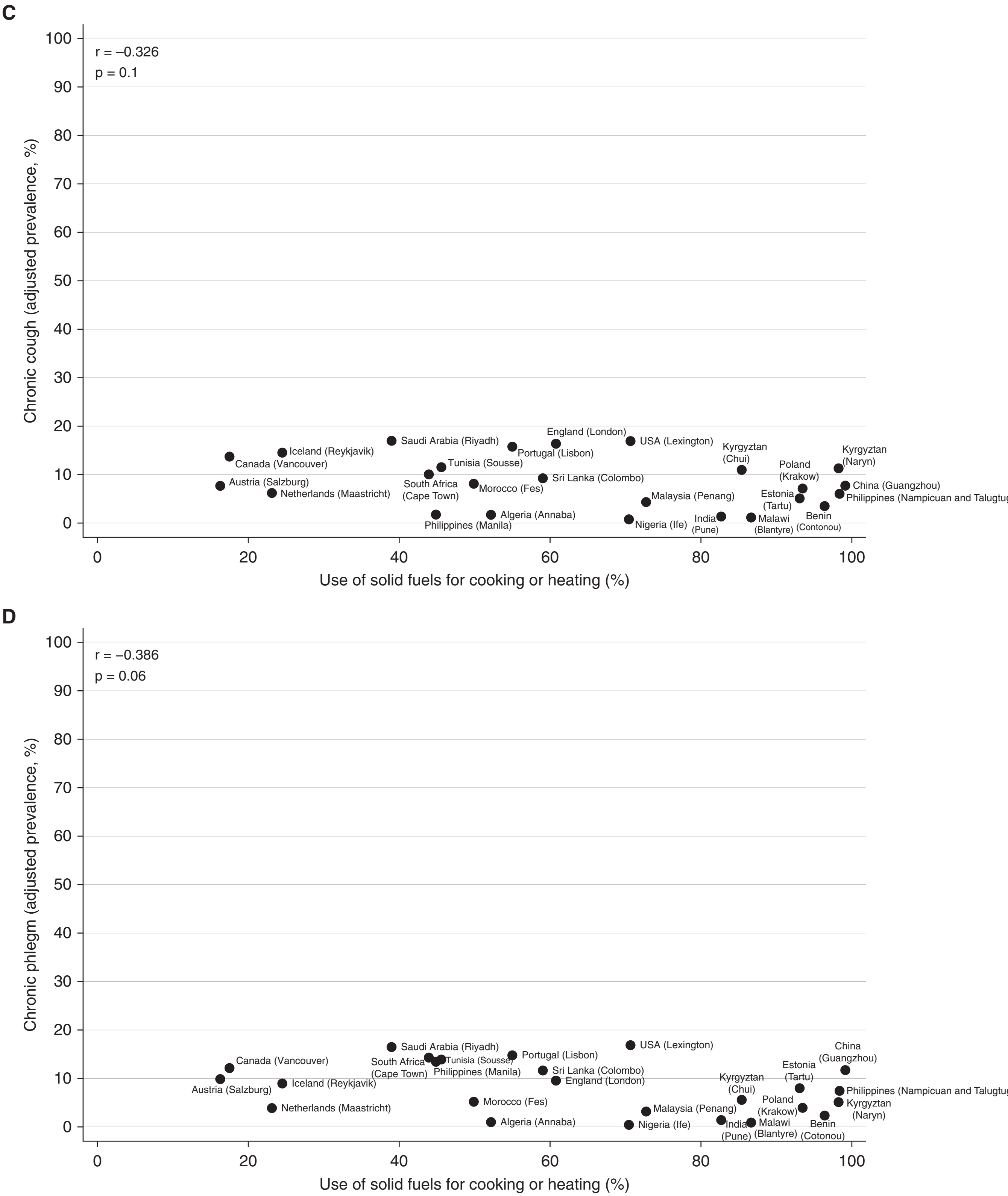


Figure 2. (Continued).

Our findings on airflow obstruction disagree with five systematic reviews (6–10). However, these reviews assessed a mixture of noncommensurate outcomes, and demonstrated clear publication bias, as acknowledged by their authors. Two other large studies have recently failed to find a positive and consistent association between airflow obstruction/COPD and solid fuel use (11, 13).

Experimental studies have explored whether there is a causal relationship between biomass smoke and airflow obstruction by reducing exposure to biomass smoke. For example, a randomized, controlled stove intervention trial among Guatemalan women, with personal exposure and spirometry measurements, reported an exposure–response relationship between exhaled carbon monoxide, used as a surrogate of recent exposure to biomass smoke, and lung function (26), but failed to show an improvement in lung function after a reduction in wood smoke exposure (27). A similar study with Mexican women reported a reduction in the decline of FEV_1 among those who used the intervention stove, but no significant improvement in the FEV_1/FVC after the intervention, and no effect in the more reliable analysis by intention to treat (15). A study in China reported a reduction in the risk of COPD defined as an FEV_1/FVC less than 0.7 after improvement in the type of stoves and fuel, but this finding was not supported by results for the continuous outcome, FEV_1/FVC (28). Although experimental studies are regarded as the gold standard for demonstrating causality, these broadly negative studies are not decisive. Airflow limitation develops over a long period of time, and these trials had limited power to show a change in decline in lung function over time.

A lack of association can never be proven, but the evidence that indoor air pollution is responsible for a substantial amount of the airflow obstruction in low-/middle-income countries comes from meta-analyses that have been overinterpreted. The observation in this study, that airflow obstruction, spirometric restriction, and chronic cough were not associated with use of solid fuels, does not mean that this exposure is not harmful to humans. We found that chronic phlegm is more likely to occur among people who used solid fuels and, although chronic bronchitis has a relatively weak effect on survival compared with the effect of poor lung function (29), chronic bronchitis has a serious impact on quality of life that may exceed the effects of poor lung function (30). Moreover, there are many other conditions that have been shown by at least some studies to be associated with high exposures to the burning of solid fuels, including childhood pneumonias and airway malignancies (31).

We cannot exclude a small effect of solid fuel use on lung function and, where this exposure is common, it could still pose a risk to health. However, there is no evidence that solid fuel use is likely to explain a substantial component of airflow obstruction or of COPD. These remain unexplained, even though they are among the most important causes of death in poorer regions of the world. An explanation for this excess mortality is still urgently needed.

In summary, in this population-based study, airflow obstruction was not associated with self-reported use of solid fuels for cooking/heating. However, this is not a definitive study. Future long-term longitudinal studies in low-income countries could inform whether airflow obstruction and mortality ascribed to COPD are temporally associated with exposure to solid fuel smoke and whether different fuels have different effects. ■

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