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Indoor and Outdoor Air Pollution and Lung Cancer in New Hampshire and Vermont

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Abstract

Indoor and outdoor air pollution is known to contribute to increased lung cancer incidence. This study is the first to address the contribution of home heating fuel and geographical course particulate matter (PM_{10}) concentrations to lung cancer rates in New Hampshire, U.S. First, Pearson correlation analysis and Geographically weighted regression were used to investigate spatial relationships between outdoor PM_{10} and lung cancer rates. While the aforementioned analyses did not indicate a significant contribution of PM_{10} to lung cancer in the state, there was a trend towards a significant association in the northern and southwestern regions of the state. Second, case-control data were used to estimate the contributions of indoor pollution and second

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hand smoke to risk of lung cancer with adjustment for confounders. Increased risk was found among those who used wood or coal to heat their homes for more than 10 winters before the age of 18, with a significant increase in risk per winter. Resulting data suggest that further investigation of the relationship between heating-related air pollution levels and lung cancer risk is needed.

Introduction

Lung cancer is the leading cause of cancer deaths particularly in men over 40 and women over 60 years of age, constituting a serious public health issue in the United States (Jemal et al. 2009). Lung and bronchial cancers are responsible for 13% of the cancer incidence in New Hampshire and 28% of the cancer mortality (Cherala 2007). Given the national 5-year relative survival rate of only 16.3% from 1999 to 2005 (all races and both genders), (Horner et al. 2009) improving our understanding of lung cancer etiology, treatment and prevention is a high priority.

Lung cancer etiology is known to be closely associated with the individual's environment, with smoking cigarettes and other tobacco products as the strongest known risk factor (Cornfield et al. 2009). Many other exposures, however, are known to also increase risk, including radon, secondhand smoke (Asomaning et al. 2008; Samet et al. 2009), arsenic, asbestos, chromium and nickel (Doll, 1955; Gibb et al. 2000; Karagas et al. 2002; Magnus et al. 1982). Indoor air pollution in the form of coarse particulate matter (PM_{10}) and toxicants resulting from fuel combustion for cooking and heating, was also reported as an environmental risk factor (Marchini et al. 2004; Cohen et al. 2005; Krewski et al. 2005). A case-control study in six European countries found increased lung cancer among individuals who used solid fuels for cooking, though they did not find similar results for heating (Lissowska et al. 2005). A cohort study from Xuanwei, China showed a long-term reduction in lung cancer incidence after replacing unvented coal burning firepits with stoves equipped with chimneys (Lan et al. 2002). Recently, a pooled analysis of the International Lung Cancer Consortium (5,105 cases and 6,535 controls) supported the hypothesis that lung cancer risk was associated with both coal and wood use (Hosgood et al. 2010).

Geographically, areas with high lung cancer rates may be the result of random effects (high number of cases in a particular region by chance alone) (Aldrich et al. 1983) or geographically disproportionate environmental exposures. These exposures include any of the aforementioned factors as well as others, including air pollution (Bilancia and Fedespina, 2009; Parodi et al. 2005; Robinson 2002). High concentrations of PM_{10}, NO_2, and O_3 are all suspected to increase risk of developing lung cancers as well as other pulmonary diseases (Schikowski et al. 2008; Forbes et al. 2009; Grant 2009; Patel and Miller, 2009; Sunyer 2009). Accordingly, levels of these pollutants are regularly monitored, especially in urban populations.

In the United States, levels of indoor air pollution from home heating have changed dramatically over the last 70 years. In 2000, 4.5% of the New Hampshire population used wood and coal as the primary method of heating their homes, while in 1940 71% used coal, coke or wood (U.S. Census Bureau, 2002).

The aim of this study was to undertake a descriptive and case-control analysis of an association between outdoor air pollution and indoor air pollution from the use of wood and coal as a primary source of heat and lung cancer incidence in Northern New England.

Methods

Outdoor Airborne Particulate matter and Lung Cancer

In order to investigate spatial distribution of outdoor airborne PM_{10} in relation to lung cancer, maps of lung cancer incidence as well as PM_{10} were created using data provided by the New Hampshire State Cancer Registry and New Hampshire Department of Environmental Services (DES) as described below.

Cancer Rate Map

A population, age and gender-adjusted map of lung cancer incidence rates was created as previously described in (Shi 2009) using data from 1993–2005 from the New Hampshire State Cancer Registry. The density was calculated for 14 individual age-gender categories using the corresponding population and case data. The densities of the 14 categories were integrated to generate an overall map. The method incorporates direct and indirect standardization using a case-side fixed bandwidth (15 km), which measures background population around each case. A restricted Monte-Carlo process was used to deal with imprecise addresses. The final map should be interpreted as showing cancer rate levels relative to each other, rather than absolute rate values (Figure 1a).

RIO Air pollution mapping

The outdoor air pollution map were created using a process called RIO (Ruimtelijke Interpolatie voor Ozon, *Spatial Interpolation of Ozone*) described by (Janssen et al. 2008). The mean annual PM_{10} concentration data for 1993 (the oldest available) at 14 sites were obtained from the State of New Hampshire DES (Figure S1)[1]. Since lung cancer usually exhibits latency between exposure to an environmental factor and presenting with disease, choosing the oldest data maximized our induction period. A NH land use map detailing the state's geography according to 23 land use types from 2001 (NH GRANIT 2001) was obtained and subsequently regrouped into 11 general classes (Figure S2)[1].

Briefly, the RIO method proceeds as follows: Maps of pollution monitoring stations are layered with maps of state-wide land use information, with each pixel of the land use map representing farming, urban, roadways, etc. A bandwidth surrounding each monitoring station is used to determine the most frequent nearby land use types. The size of the bandwidth is determined by assessing how well a histogram of land use types using different sizes (1 km, 2 km, 3km (Figures S3, S4 and S5)[1]) distinguishes between urban and rural locations (southeast NH is urban, while north and southwest NH are rural). Based on this analysis, the 1 km bandwidth was chosen to create our air pollution map.

The number of pixels of each land use type within each buffered monitoring station was obtained using zonal statistics. Each land use type was assigned a weight coefficient (alpha value) based on how often it occurred within 1 km of each monitoring station and the corresponding PM_{10} value measured there. This provides an approximation of how much each land use type is expected to contribute to local air pollution. The weights were then applied to the entire map to interpolate PM_{10} from land use following the procedure found in (Janssen et al. 2008). The map was smoothed using kriging in ArcMap 9.3 using a 12 point bandwidth.

Resulting state-wide PM_{10} estimates were confirmed by cross-validation, where each monitoring station was left out in turn, and their PM_{10} level was estimated using results

[1]All Supplementary material is available online at [INSERT ARTICLES HYPERLINKED DOI].

from the other 13 stations (Table S1)[1]. A paired t-test between estimated and actual values was not significant.

Geographically weighted logistic regression

Due to differences in bandwidth size between the cancer rate map and the RIO map (which shows much tighter regions of high air pollution), a second map was interpolated using ordinary kriging within ArcMap 9.3 and the 14 air pollution stations. Subsequently, 1000 random points were generated on the maps surface and used to extract PM_{10} and rate data at these points. Geographically weighted regression (GWR) analysis within ArcMap 9.3 was then used to investigate spatial variation in the coefficients of contribution of PM_{10} in relation to the statewide lung cancer rate incidence rate map. GWR is a method for conducting regression analysis within different regions of a geographical area using a moving bandwidth. The contribution of each individual to the local parameter estimates is weighted according to their distance from the center of the bandwidth. This procedure used a fixed bandwidth of 0.399 degrees as optimized within the spgwr package in R v 2.7.2.

Population-based case-control study

A population-based case-control study of lung cancer, the New England Lung Cancer Study (NELCS), was conducted in seven New Hampshire counties (Belknap, Carroll, Cheshire, Coos, Grafton, Merrimack, and Sullivan) and three Vermont counties (Orange, Windham, and Windsor). Incident cases of lung cancer (30–74 years of age) were identified from 2005 to 2007 using the New Hampshire State Cancer Registry and the Dartmouth-Hitchcock Tumor Registry of the Norris Cotton Cancer Center and Dartmouth-Hitchcock Medical Center in Lebanon, NH. Of 454 eligible cases, 24 (5%) could not be reached; 52 (11%) were too ill to be interviewed; 101 (22%) refused participation, and 277 cases were interviewed, for a 61% participation rate (Heck et al. 2009).

Control participants were identified using a commercial database from Experian for the contiguous 10-county study area for the period 2005–2006. For each potential control, the database contained the full name, date of birth (or estimated age), address, gender, and telephone number. Based on a marginal count comparison with US Census Bureau data for the same time period, 73.4% of women and 72.4% of men in the NELCS study area were accounted for in the commercial database. Control eligibility was the same as for cases except for the presence of lung cancer. Controls were randomly selected from the commercial database and frequency matched to lung cancer cases within 5-year age group and gender. Of the 547 eligible controls selected at random, 123 (22%) could not be reached, 11 (2%) were too ill to be interviewed, and 162 (30%) refused participation. A total of 251 controls completed the interview for a 46% participation rate.

The study complied with all applicable requirements of the Dartmouth Medical School ethical review board (Committee for the Protection of Human Subjects), the Norris Cotton Cancer Center, the State of New Hampshire, and written informed consent were obtained from all participants prior to participation. All in-person interviews were conducted by trained interviewers using a structured questionnaire covering demographic, lifestyle, medical history, and a lifetime residential history calendar. Each individual was asked whether they had ever used wood or coal stoves for home heating before and after 18 years of age. The number of winters that wood or coal was used as the main source of heat before and after the age of 18 was also assessed. Secondhand smoke exposure was analyzed in a similar way, using data on the number of years of regular exposure to secondhand smoke. For the entire dataset (VT and NH, n=528), a logistic regression analysis was completed to determine the contribution of indoor home heating type on lung cancer risk (Table 2). Analyses were adjusted for age, gender, secondhand smoke and pack years of smoking.

The RIO map (described above) was used to assess the association between outdoor airborne PM_{10} and risk of lung cancer. Average PM_{10} levels in a 5km radius were obtained for each individual case or control subject in the New England Lung Cancer study who resided in New Hampshire using buffering as implemented in ArcMap 9.3 (PM data not available for Vermont). An analysis was performed with restriction to individuals within the more populated region of the state - southern NH (n=303). Subjects were assigned PM_{10} measures within 5 km of their supplied address and logistic regression was carried out relating PM_{10} levels and cancer status. These analyses were adjusted for smoking (pack years), age (years) and gender.

Results

The maps created using the RIO method for PM_{10} as well as the cancer rate map are shown in Figures 1a and 1c. Figure 1b shows the PM_{10} map as interpolated directly from the sampling sites without using the RIO method. Darker shading represents higher rates or more concentrated PM_{10} levels for each map respectively. Relatively higher lung cancer incidence rates are noticeable in several locations including pockets in the northern and eastern portions, and the east-central portion of the state corresponding to Lincoln, NH. High air pollution and high cancer rates are overlapping in the southeastern portion of the state and is consistent with the most urban and industrialized areas, such as the region surrounding the Merrimack River which flows from the south-central portion of New Hampshire. Regions of high air pollution in the north and west are also present, while the north-central region of the state shows low rates (wooded White Mountain National Park region). A merged, 3d version of the maps is shown in Figure 2 along with wind direction data (obtained from New Hampshire Department of Environmental services). Wind rosettes shows % of winds within a certain speed that originate from each direction. Lung cancer incidence rates in this map are shown as peak heights (scaled by 0.05 for ease of viewing) while PM_{10} concentrations are shown as colors. The Pearson correlation using the 1000 random points was not statistically significant ($\rho = 0.21$, Figure S6[1]). The map demonstrates that there are regions where high air pollution and high cancer rates co-occur though this is not consistently the case. The highest cancer rate peak is located in the north, just beyond the city of Berlin.

In the geographically weighted regression analysis, PM_{10} was associated with lung cancer rates in the north and southwestern regions. Figure 3 shows the interpolated coefficients as a background to the 1000 randomly placed points, colored according to residual values. Residuals were spatially auto-correlated (Moran's I = 0.57, $p<0.0001$) indicating that PM_{10} does not completely explain the variability in the model of lung cancer incidence rates.

Using the New England Lung Cancer Study, a population-based case-control study, the hypothesis that higher levels of airborne PM_{10} was associated with elevated lung cancer risk was further investigated. This study allows us to account for potentially confounding factors such as age, gender and smoking status on an individual-level. Demographic data for the study population are shown in Table 1. Males and females comprised 41% and 59% of the lung cancer controls and 45% and 55% of the cases, respectively. Most participants were between the ages of 55 and 70 years old, and few (6 controls and 9 cases) were below 40 years old. High levels of smoking were more common among cases than controls, with 13% of controls and 43.5% of cases having smoked greater than 54 pack years. Overall, PM_{10} concentration within 5km was unrelated to lung cancer risk after adjustment for age (year), gender and smoking status (pack years) (OR=0.96; 95% CI, 0.83 – 1.12; p=0.64).

The association between lung cancer risk and indoor air pollution from use of wood or coal for heating was next examined. First, the relationship between ever/never having heated with wood or coal before and after the age of 18 was investigated using the full dataset. Ever having used wood or coal stoves as an adult was associated with lower risk (OR = 0.60; 95% CI, 0.38 – 0.95; p=0.03), compared to never use.

However, after restricting to the population who had used wood or coal as the primary source of heating in their homes below 18 years old, an increased risk per winter (OR = 1.07; 95% CI, 1.01 – 1.12; p = 0.02) was noted with an especially high risk among those who used wood or coal for more than 10 years (OR = 2.43; 95% CI, 1.26 – 4.67; p = 0.008).

An investigation of secondhand smoke exposure among cases and controls discerned a significant effect among those over 18 years of age (Table 3). This effect was evident among those who were ever or never exposed to secondhand smoke (OR = 2.06; 95% CI, 1.34 – 3.17; p = 9.9 E-4) and when taking into account the number of years of exposure (OR = 1.02; 95% CI, 1.01 – 1.04 per year; p = 2.6 E-3).

Discussion

Despite the overall lack of statistical correlation, high lung cancer incidence rates and the PM_{10} air pollution levels showed a trend towards a positive association particularly in the northern parts of the state. This region is where the highest PM_{10} and highest lung cancer rates are both located. The town of Berlin (the most populated town in this northern NH rural region) has been known to have high levels of pollution due to the long-time paper milling industry that existed there throughout the majority of the 20th century. Higher lung cancer rates were also observed in the West/Central portion of the state, particularly around the town of Lincoln, NH. There was no statistical correlation between pollution levels and cancer rates in this area, possibly due to other environmental risk factors in that region, or a lack of sampling stations near that location that prevented accurate levels of PM_{10} from being discerned.

Using the RIO method that incorporated land use, it was possible to create a reasonably accurate air pollution map given the sparseness of the sampling points. This map was much more detailed than results using typical interpolation methods such as ordinary kriging. Several assumptions were required to implement this method. The first is that air pollution data from 1993 maintained spatial consistency over time. Ideally, the scale of time for the pollution measurements and land use would come before the expected lag time for cancer initiation period and subsequent diagnosis. Another assumption is that the PM_{10} levels surrounding individual participants in the last phase of the study represent overall PM_{10} exposure. Since most of the individuals in the study were older than 60 years of age, they may have likely had various air pollution exposures over time due to changes in work and living conditions or locations.

An analysis of indoor air pollution from wood and coal use in home heating was also performed. The results suggest increased risk among those who more frequently used wood or coal stoves as the primary source of heat during childhood and adolescence. The results showing a protective effect for using wood stoves versus not are likely due to an unmeasured confounder that could not be accounted for here. Wood stove use as a primary source of home heating in northern New England was 71% in 1940, and has decreased over the course of the century (U.S. Census Bureau 2002). The type of wood stoves have likely also changed with the invention of stoves that burn cleaner and release less indoor pollution than they did during the mid 20th century. The evidence that wood stove use prior to the age of 18 is most associated suggests that behaviors in wood stove use either changed dramatically in the latter part of the century, or that indoor pollution created by wood stoves exert a greater effect during early development, or both (Zelikoff et al. 2002).

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The combined results from these analyses suggest that both indoor and outdoor air quality influence risk of lung cancer in this study region and sample population, although cigarette smoking is certainly the largest contributor. Increased monitoring of outdoor air pollution in the Lincoln, NH region may lend clues to their high cancer rate, while region-wide air pollution reduction is important to reducing general incidence.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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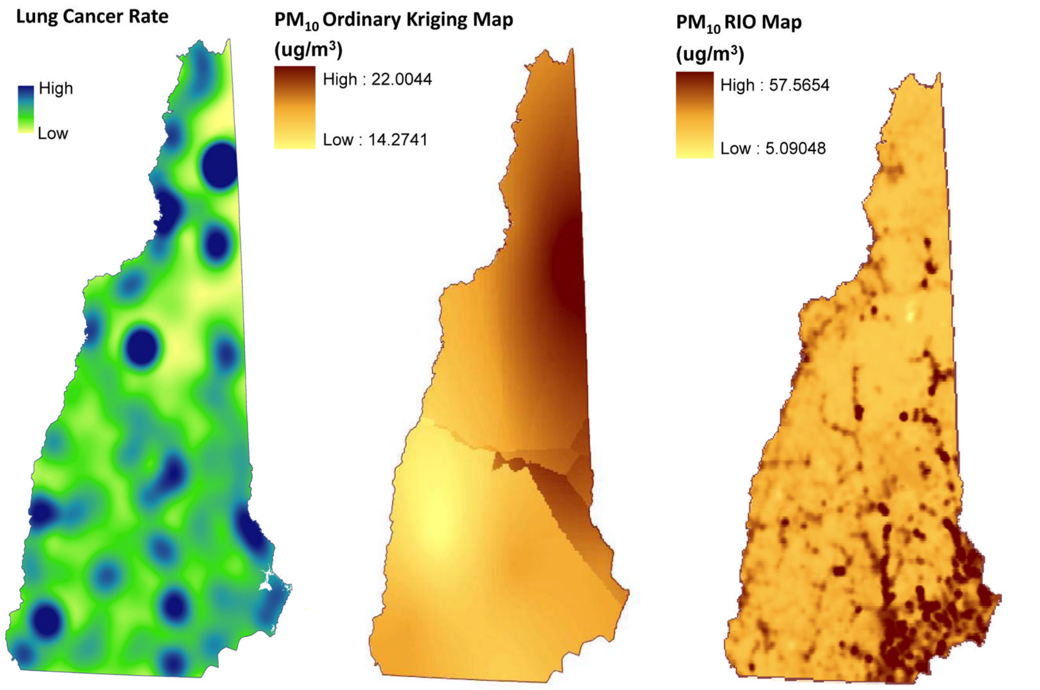

Figure 1.

1a) The NH rate map as created using the New Hampshire State Cancer Registry data. Darker blue shades represent relatively higher rates than regions of green or yellow. *1b)* PM_{10} map interpolated using ordinary kriging of measured PM_{10} values at 14 stations in New Hampshire. *1c)* RIO map of PM_{10} interpolated using land use data and PM_{10} values recorded at the 14 measurement stations.

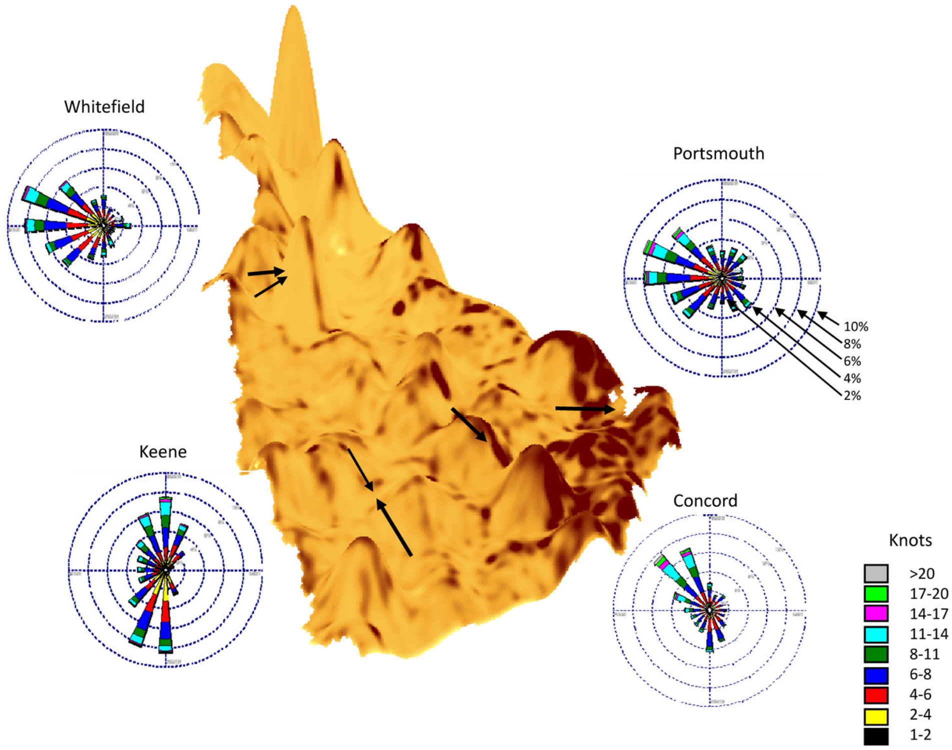

Figure 2.
Combined 3d RIO and rate map with wind rosettes showing wind speed and origin. Color is PM_{10} concentration, while peak height (scaled at 0.05 actual peak height) represents relative cancer rates.

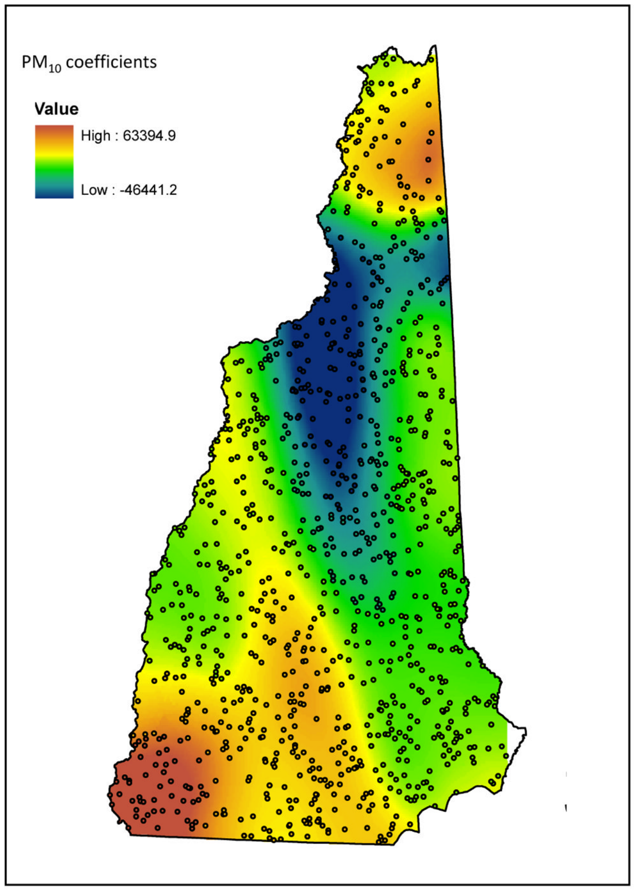

Figure 3.

Results of geographically weighted regression analysis between PM_{10} and relative cancer rates. Colors show interpolated coefficients, while 1000 random points are displayed with color representing residual values at each point, demonstrating a trend towards spatial autocorrelation in some regions of the state.

Table 1

Population characteristics- Demographic information for the 528 cases and controls used in the logistic regression portion of the study.

	Lung Cancer Cases N=277 N (%)	Controls N=251 N (%)
Gender		
Males	124 (45)	103 (41)
Females	153 (55)	148 (59)
Reference age		
<40	9 (1)	6 (3)
40–55	55 (20)	54 (22)
55–70	158 (57)	124 (49)
>70	61 (22)	65 (26)
Smoking status		
Never	14 (5)	102 (41)
Ever	263 (95)	149 (59)
Pack years		
25th percentile (<1.75 pack years)	1 (0.5)	12 (8)
25–50th percentile (1.75 –31.25 pack years)	50 (19)	80 (56)
50th–75th percentile (31.25 –54 pack years)	95 (37	33 (23)
>75th percentile (>54 pack years)	113 (43.5)	18 (13)

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Table 2

Lung cancer risk and primary use of wood or coal for heating.

Number of winters primarily heating with wood and/or coal	Cases: Mean winters	Controls: Mean winters	OR (95% CI)*	p-value*
age < 18	13.93	12.58	**1.07 (1.01,1.12)**	**0.02**
<25% (1–9 winters)			1.0 (ref)	
≥25% (10+ winters)			**2.43 (1.26, 4.67)**	**0.008**
age > 18	17.41	15.78	1.0 (0.98,1.02)	0.93
age <18 + age>18			1.0 (0.98,1.01)	0.57

*Adjusted for age, gender, smoking (pack years), and secondhand smoke.

Table 3

Lung cancer risk and secondhand smoke exposure.

Ever Exposed to Second-Hand Smoke at Home	Cases N (%)	Controls N (%)	OR (95% CI)*	p-value*
Never	17	38	1.00 (ref group)	NA (ref group)
Ever				
age < 18	238	192	1.31 (0.78,2.21)	0.31
age > 18	231	122	**2.06 (1.34,3.17)**	**9.9E-04**
age < 18 & age >18	176	102	**1.93 (1.33, 2.82)**	**5.7E-04**
Number of Years Exposed to Second-Hand Smoke at Home	Mean	Mean	OR (95% CI)* (increase per year)	p-value*
age < 18	14.65	12.64	1.01 (0.99, 0.33)	0.33
age > 18	18.75	10.2	**1.02 (1.01, 1.04)**	**2.6E-03**
age <18 + age>18	33.40	22.84	**1.02 (1.01, 1.03)**	**2.9E-03**

*Adjusted for age, gender, smoking (pack years).