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Incidence and mortality risk for respiratory tract cancer in the city of São Paulo, Brazil: Bayesian analysis of the association with traffic density

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In memoriam of Clarice U. de Freitas.

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ABSTRACT

Background: There is evidence that exposure to traffic-related air pollution is related to the incidence of and mortality associated with lung cancer. The aim of this study was to perform a spatial analysis, with a Bayesian approach, to test the hypothesis that high traffic density is associated with increased respiratory tract cancer incidence and mortality risk among individuals over 20 years of age residing in the city of São Paulo, Brazil.
Methods: We employed data from two different databases: the São Paulo Municipal Population-Based Cancer Registry (2002–2011 cancer incidence data); and the Mortality Database of the São Paulo Municipal Health Department (2002–2013 cancer mortality data). The relationships between the number of cases of respiratory tract cancer in each area analyzed and the standardized covariates—traffic density and the Municipal Human Development Index (MHDI)—were evaluated with a Besag–York–Mollié ecological model with relative risks (RRs) estimates.
Results: Per 1-unit standard-deviation increase in traffic density and in the MHDI, the RR for respiratory tract cancer incidence was 1.07 (95% CI: 1.02–1.13) and 1.25 (95% CI: 1.18–1.32), respectively, whereas the RR for mortality was 1.04 (95% CI: 0.99–1.09) and 1.23 (95% CI: 1.16–1.30), respectively.
Conclusion: Our findings support the hypothesis that residing in areas with high traffic density is associated with increased respiratory tract cancer incidence and mortality risk in the city of São Paulo.

1. Introduction

According to the World Health Organization (WHO), there were approximately 3.7 million deaths attributable to environmental air pollution in 2012, 88% of those deaths occurring in low- or middle-income countries and approximately 6% being from lung cancer [1]. In an estimate of the patterns of cancer incidence and mortality in 40 European countries in 2012, lung cancer was found to be the fourth most common type of cancer, with 410,000 new cases, and the leading cause of death from cancer, with 353,000 deaths [2]. According to the Brazilian National Cancer Institute, there were an estimated 17,330 and 10,890 new cases of tracheal, bronchial, or lung cancer among men and women, respectively, in Brazil in 2016, corresponding to an estimated incidence of 17.49 cases/100,000 men and 10.54 cases/100,000 women [3].

Although smoking is considered a potential risk factor for lung cancer, exposure to environmental carcinogens has been associated with the occurrence of the disease. The International Agency for Research on Cancer (IARC) has stated that there is strong evidence that diesel engine exhaust is carcinogenic to humans, therefore classifying its constituents as Group 1 carcinogens [4]. The IARC subsequently concluded that exposure to elevated levels of outdoor air pollution, especially particulate matter, increases the risk of lung cancer, being both classified as carcinogenic to humans (Group 1) [5].

There is evidence of associations between exposure to traffic-related air pollution and various health outcomes, as outlined in a review study

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conducted by the Health Effects Institute [6], which identified the zones of exposure to such pollution as areas located 300–500 m from a major road. A number of studies have found that long-term exposure to particulate matter or other constituents of traffic-related air pollution correlates with the incidence of lung cancer [7–13], as well as with the associated mortality [14–20].

Most studies that have addressed the impacts of air pollution and the occurrence of cancer have been cohort studies, few studies having performed spatial analyses to investigate associations between the two [21,22]. Within a spatial analysis, the use of Bayesian modeling has been shown to be an effective tool for mapping diseases, providing more accurate risk estimates, using a combination of covariate data and a set of spatial random effects to model any overdispersion or spatial correlation in the disease data [23–25]. Therefore, the objective of this study was to perform a Bayesian analysis to test the hypothesis that the incidence of and mortality related to respiratory tract cancer are higher in areas with higher traffic density in the city of São Paulo, Brazil.

2. Methods

2.1. Study site

The city of São Paulo occupies an area of 1,521.11 km^2 and has a population of approximately 12 million [26]. The vehicle fleet is the main source of air pollution, 8.4 million registered vehicles circulating daily on the 18,000 km of roads in the city, which are denser in the central region [27].

This study used the operational division of the city, into 310 weighting areas, established by the Brazilian Institute of Geography and Statistics. Each weighting area, in turn, is a geographic unit formed by a grouping of census areas for the application of procedures to calibrate the weights in order to produce estimates consistent with known information related to the population as a whole. To provide validity in the estimates, it is necessary to include a certain number of residences and residents. Therefore, the minimum size of a weighted area was defined as 400 occupied households [28].

2.2. Identification of cases

Data were obtained from two different databases: the São Paulo Municipal Population-Based Cancer Registry (for 2002–2011 cancer incidence data); and the Mortality Database of the São Paulo Municipal Health Department (for 2002–2013 cancer mortality data). The study included all cases meeting the International Classification of Diseases (ICD-10) criteria for malignant neoplasms of the respiratory system—code C32 (malignant neoplasm of larynx), C33 (malignant neoplasm of trachea), or C34 (malignant neoplasm of bronchus and lung)—and occurring in individuals over 20 years of age. This age cut-point is justified by the fact that we considered that individuals had been exposed to air pollutants from birth, with a minimum latency period of 20 years. Previous local studies [7,29] found a correlation between air pollution and neoplasms of larynx and lung in São Paulo proving evidence for the inclusion of neoplasms of larynx and trachea in addition to lung cancer.

In the incidence database, a total of 15,435 records were geocoded by the address of the individual, 15,411 (99.84%) corresponding to cancers of the respiratory tract in the age group under study. Of the cases evaluated, 21.43%, 0.37%, and 78.20% met the criteria for diagnoses corresponding to the ICD-10 codes C32, C33, and C34, respectively. In the mortality database, a total of 19,513 were geocoded by postal code. Of those, 19,500 (99.93%) were cases of respiratory tract cancer in individuals over 20 years of age, diagnoses corresponding to the ICD-10 codes C32, C33, and C34 accounting for 15.16%, 0.24%, and 84.60%, respectively. Postal code contains equivalent geographic information for the purposes of exposure assignment using weighting areas. We used the existing set of georeferenced points within the city of São Paulo (Multispectral, São Paulo, Brazil) and the ArcGIS software, version 9.3 (Esri, Redlands, CA, USA).

2.3. Evaluation of exposure

Traffic density for the year 2008 was used as the exposure variable. The databases for traffic volume on the roadways of the city of São Paulo were constructed with data obtained from the São Paulo Department of Transportation, which counts vehicles on various streets, and complemented with traffic data for 681 streets evenly distributed throughout the city, vehicle counts being obtained with the same method used by the Department of Transportation: no counts were made near traffic lights or when traffic was stalled. Roadways on which no actual counts were obtained were assigned counts based on the mean values determined for each function: expressway, arterial-1, arterial-2, arterial-3, collector-1, collector-2, and local [30].

The Municipal Human Development Index (MHDI) for the year 2010 was used as an indicator of socioeconomic status. In calculating the MHDI, we grouped its three components (longevity, income, and education) by geometric mean, according to the calculation methodology of the United Nations Development Programme [31], to generate an indicator of development, which ranges from 0 to 1. For the longevity component, we used data referring to mortality in the city for the triennium 2009–2011, obtained from the São Paulo Municipal Health Department. For the income and education components, we used data from the 2010 census [28].

2.4. Statistical analysis

Using a Besag–York–Mollié ecological model [32], we evaluated the relationships that the standardized covariates (traffic density and MHDI) had with the number of new cases of respiratory tract cancer, as well as with the number of associated deaths, in each weighting area. In the likelihood estimation, a Poisson distribution was used. To express the results in terms of relative risk (RR), we included the logarithms for the expected number of new cases and the expected number of deaths, respectively, obtained by indirect standardization [32]. The collinearity between covariates was measured in terms of the Variance Inflation Factor (VIF), using a threshold of 3 [33]. We used vague priors for the fixed effects (vague normal = N(0, 0.001)), whereas the priors for the accuracy of the logarithms for the structured and unstructured residuals were given by the log-gamma (lognormal = 1, 0.5), as previously described [34]. We also built an intercept-only model—equivalent to the previous one but without covariates—to estimate the crude RR for each area and to make a visual comparison between the estimates provided by the two models. The fit of the two models was compared on the basis of the deviance information criterion (DIC). The analyses were made in the program R, version 3.4.2 [35], using the integrated nested Laplace approximation (INLA) packages 17.06.20 [36], INLAOutputs, version 1.2.7 [37], ggplot2, version 2.2.1 [38], and ggsn, version 0.4.7 [39].

3. Results

The total traffic density and the MHDI values for the city of São Paulo are shown in Fig. 1. The roadways and traffic are considerably more dense in the central region of the city, areas of low and very low traffic intensity being seen in its extreme northern, eastern, and southern regions. The socioeconomic indicator (MHDI) also showed higher values in the central regions. However, in some regions, affluent areas are adjacent to poorer areas.

Table 1 shows the modeling results for the incidence of and mortality associated with respiratory tract cancer. Collinearity was not considered problematic because the VIF for the traffic density and MHDI was 1.29 (incidence) and 1.31 (mortality). In the analysis of the incidence of respiratory tract cancer, the ecological model had a better