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Associations between fine particulate matter and mortality in the 2001 Canadian Census Health and Environment Cohort

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ABSTRACT

Background: Large cohort studies have been used to characterise the association between long-term exposure to fine particulate matter ($PM_{2.5}$) air pollution with non-accidental, and cause-specific mortality. However, there has been no consensus as to the shape of the association between concentration and response.
Methods: To examine the shape of this association, we developed a new cohort based on respondents to the 2001 Canadian census long-form. We applied new annual $PM_{2.5}$ concentration estimates based on remote sensing and ground measurements for Canada at a 1 km spatial scale from 1998 to 2011. We followed 2.4 million respondents who were non-immigrants aged 25–90 years and did not reside in an institution over a 10 year period for mortality. Exposures were assigned as a 3-year mean prior to the follow-up year. Income tax files were used to account for residential mobility among respondents using postal codes, with probabilistic imputation used for missing postal codes in the tax data. We used Cox survival models to determine hazard ratios (HRs) for cause-specific mortality. We also estimated Shape Constrained Health Impact Functions (a concentration-response function) for selected causes of death.
Results: In models stratified by age, sex, airshed, and population centre size, and adjusted for individual and neighbourhood socioeconomic variables, HR estimates for non-accidental mortality were HR = 1.18 (95% CI: 1.15–1.21) per 10 μg/m^3 increase in concentration. We observed higher HRs for cardiovascular disease (HR = 1.25; 95% CI: 1.19–1.31), cardio-metabolic disease (HR = 1.27; 95% CI: 1.21–1.33), ischemic heart disease (HR = 1.36; 95% CI: 1.28–1.44) and chronic obstructive pulmonary disease (COPD) mortality (HR = 1.24; 95% CI: 1.11–1.39) compared to HR for all non-accidental causes of death. For non-accidental, cardio-metabolic, ischemic heart disease, respiratory and COPD mortality, the shape of the concentration-response curve was supra-linear, with larger differences in relative risk for lower concentrations. For both pneumonia and lung cancer, there was some suggestion that the curves were sub-linear.

Abbreviations: AMDB, Amalgamated Mortality Database (Statistics Canada); AQMS, Air Quality Management System; CanCHEC, Canadian Census Health and Environment Cohort (1991 and 2001); CD, Census Division; COPD, Chronic obstructive pulmonary disease; DA, Dissemination area; DB, Dissemination block; GEOS, Goddard Earth Observing System; MODIS, Moderate Resolution Imaging Spectroradiometer; NAC, Non-Accidental; PCCF+, Postal Code Conversion File Plus (Statistics Canada); SCHIF, Shape-Constrained Health Impact Function; SIN, Social insurance number

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Conclusions: Associations between ambient concentrations of fine particulate matter and several causes of death were non-linear for each cause of death examined.

1. Introduction

Fine particulate matter ($PM_{2.5}$) is a complex mixture of particles (e.g., sulfate, smoke, and dust) smaller than 2.5 µm in aerodynamic diameter, and is one of the main components of ambient air pollution. Exposure to $PM_{2.5}$ air pollution was estimated by the Global Burden of Disease study to be responsible for 4.2 million deaths and 108 million disability-adjusted life years in 2015 (GBD, 2016). Several large epidemiological cohort studies have linked long-term exposure to $PM_{2.5}$ to mortality. In the United States, for example, the American Cancer Society cohort study estimated increased relative risks of non-accidental mortality (RR = 1.06, 95% CI: 1.02–1.11 per 10 $\mu g/m^3$ increase), as well as cardiopulmonary and lung cancer mortality associated with exposures to $PM_{2.5}$ (Pope et al., 2002). In an analysis of 22 European cohorts (European Study of Cohorts for Air Pollution Effects: ESCAPE), pooled hazard ratios (HRs) for non-accidental mortality were 1.07 (95% CI: 1.02–1.13) per increase of 5 $\mu g/m^3$ (Beelen et al., 2014).

Despite relatively lower concentrations of air pollution in Canada, previous studies have also indicated that exposure to $PM_{2.5}$ is associated with increased risk of non-accidental and cardiovascular mortality. In Crouse et al. (2012), the 1991 Canadian Census Health and Environment Cohort (1991 CanCHEC) followed 2.1 million census respondents during a 10 year follow-up period, and observed associations between ambient $PM_{2.5}$ and non-accidental and cardiovascular mortality. However, there were several limitations of this study. First, $PM_{2.5}$ estimates were based on a model that had relatively coarse (approximately 10 km grid) spatial resolution, thereby possibly contributing to exposure misclassification, particularly in smaller cities (i.e., less than 10 km across). Second, estimates of exposure were assigned based on postal codes at baseline, therefore not accounting for residential mobility during follow-up. Third, exposure estimates were based on a 2001–2006 average, meaning that changes over time were not considered, and the vintage of the exposure data did not match that of the follow-up period. Fourth, behavioural covariates such as smoking were not considered in the model. To overcome some of these limitations, a follow-up study of the same cohort followed respondent mobility and assigned a 7-year moving average of $PM_{2.5}$ exposure to respondents, based on year-adjusted $PM_{2.5}$ estimates (Crouse et al., 2015). Restricted cubic splines with three knots were used to examine the association between $PM_{2.5}$ and non-accidental mortality. These relative risk predictions suggested that differences in risk were greater for lower concentrations compared to higher concentrations, suggesting a supra-linear association. A separate study using the Canadian Community Health Survey-Mortality cohort accounted for behavioural covariates (e.g., smoking) directly, and reported only a small effect upon hazard ratio estimates for the association between $PM_{2.5}$ and mortality (Pinault et al., 2016a). Again using restricted cubic splines with three knots, a supra-linear association was observed. There was no suggestion of a sub-linear association at lower concentrations in either study.

The purpose of the present study is to provide an updated analysis using a larger and more recent cohort: the 2001 Canadian Census Health and Environment Cohort (2001 CanCHEC), which overcomes many of the remaining limitations of previous studies. We assigned exposures based on a relatively fine-scale $PM_{2.5}$ model (approximately 1 km grid), which incorporated both remote sensing estimates and ground observations. Then, we generated a complete annual residential history for all cohort members from a linkage to postal codes in tax records (as in Crouse et al., 2015). As a novel contribution, we imputed missing postal codes in the residential history with a probabilistic algorithm. As in Crouse et al., 2015, exposures were based on year-adjusted estimates from 1998 onwards, and the vintage of the exposure data matched that of the follow-up period. We also sought to more thoroughly examine the shape of the concentration-response curve beyond using restricted cubic splines with a pre-specified small number of knots (i.e. 3). This analysis also builds on the previous work by Nasari et al. (2016), where an older (1991) CanCHEC was used with coarsely-scaled exposure data and where multiple causes of death were not examined. There is specific interest in the shape of the association at very low concentration in order to conduct burden analysis (GBD, 2016). The concentration-response relationship at low levels is an issue of particular interest in Canada, as a country with relatively low levels of $PM_{2.5}$, and in many global regions that are approaching these lower ranges of exposure.

2. Materials and methods

2.1. Data

The 2001 CanCHEC is an analytical dataset that was formed through the linkage of the 2001 Census long-form questionnaire to tax and mortality databases. The 2001 Census long-form questionnaire is distributed to nearly 20% of Canadian households, although it is distributed to nearly 100% of households in remote areas and enumerated Indian reserves (Statistics Canada, 2003). The linkage methodology and cohort have been described elsewhere (Pinault et al., 2016b). Briefly, non-institutionalized respondents to the 2001 Census long-form questionnaire that lived in Canada were considered in scope for linkage (n = 4,500,200). Of these, 78.6% (n = 3,537,500) were linked through standard deterministic and probabilistic linkage techniques (Fellegi and Sunter, 1969) using sex, date of birth, postal code, and marital status to income tax files (T1 Personal Master File, Canada Revenue Agency) to obtain an annual postal code history and a Social Insurance Number (SIN). The proportion of respondents successfully linked to tax files was lower for younger adults, Aboriginal respondents, and persons who had moved in the previous year, possibly due to being less likely to have filed taxes and/or difficulties in matching linkage keys (e.g., postal codes). The false-positive error rate in the linkage was less than 0.2% (Pinault et al., 2016b).

Subsequently, tax-linked Census respondents were deterministically linked to the Amalgamated Mortality Database (AMDB) using SINs. The AMDB is a dataset that includes death records from both the Canadian Mortality Database (which compiles provincial and territorial hospital death registries beginning in 1950) and deaths recorded in tax files. Deaths that occurred between census day (May 15, 2001) and December 31, 2011 were eligible for linkage. A total of 347,000 deaths were recorded during the 10.6 year follow-up period. Mortality statistics for the cohort were broadly consistent with patterns observed in the 1991 CanCHEC and national vital statistics (Wilkins et al., 2008; Pinault et al., 2016b). Members of the final cohort were slightly more likely to be married or common-law, have higher income or higher educational attainment, or be employed than were the general Canadian population (Pinault et al., 2016b).

Respondents were assigned estimates of exposure to fine particulate matter ($PM_{2.5}$), derived from a national model (van Donkelaar et al., 2015). Briefly, total column optical aerosol depth retrievals from the Moderate Resolution Imaging Spectroradiometer (MODIS) were related to near-surface $PM_{2.5}$ using the GEOS-Chem chemical transport model, and a geographically weighted regression applied to incorporate ground-level observations, thereby adjusting for bias in the remote-sensed estimates. Yearly (2004–2012) averages in estimated surface $PM_{2.5}$ at approximately 1 km^2 resolution were obtained (van Donkelaar et al., 2015), and extended back in time to 1998 by applying inter-