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Long-term exposure to fine particulate matter air pollution and type 2 diabetes mellitus in elderly: A cohort study in Hong Kong☆,☆☆,★

Hong Qiu[a], C. Mary Schooling[a], Shengzhi Sun[a], Hilda Tsang[a], Yang Yang[a], Ruby Siu-yin Lee[b], Chit-Ming Wong[a], Linwei Tian[a,*]

[a] School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong
[b] Elderly Health Service, Department of Health, Hong Kong

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ABSTRACT

Background: Evidence for the link between long-term air pollution exposure and occurrence of diabetes is limited and the results are mixed.
Objectives: We aimed to assess the association of long-term residential exposure to fine particulate matter ($PM_{2.5}$) with the prevalence and incidence of type 2 diabetes mellitus (DM).
Methods: This is a prospective cohort study. We studied 61,447 participants of the Chinese Elderly Health Services cohort in Hong Kong enrolled 1998–2001 and followed participants without DM at baseline to 31 December 2010 to ascertain the first hospital admissions for type 2 DM. Yearly mean residential $PM_{2.5}$ exposure was predicted based on satellite data. Logistic regression and time-varying Cox regression model were used to evaluate the prevalence and incidence risk of DM associated with $PM_{2.5}$ while adjusting for potential individual and neighborhood confounders.
Results: There were 61,447 participants included in the study of prevalent DM, and in 53,905 participants without DM at baseline we studied incident type 2 DM. Over a mean follow-up of 9.8 years, we ascertained 806 incident cases of type 2 DM. After adjusting for potential confounders, the odds ratio (OR) for every interquartile range (3.2 μg/m^3) increase of $PM_{2.5}$ concentration was 1.06 (95% confidence interval (CI): 1.01–1.11) for prevalent DM, while the corresponding hazard ratio (HR) was 1.15 (95% CI: 1.05–1.25) for incident type 2 DM.
Conclusions: Long-term exposure to high levels of $PM_{2.5}$ may increase the risk of both prevalence and incidence of type 2 diabetes mellitus in Hong Kong elderly population.

1. Introduction

An estimated 422 million adults were living with diabetes in 2014 globally compared to 108 million in 1980, according to the WHO Global Report on Diabetes. The global age-standardized prevalence of diabetes has nearly doubled since 1980, rising from 4.7% to 8.5% in the adult population (World Health Organization, 2016). Type 2 diabetes mellitus (DM), or adult-onset diabetes, is a group of metabolic disorders characterized by high blood glucose levels caused by a combination of resistance to insulin action and an inadequate compensatory insulin secretory response, which is the most common type of DM accounting for about 90–95% of all DM cases (American Diabetes Association, 2014).

Type 2 DM is undoubtedly attributable to modifiable lifestyle behaviors and can be prevented or delayed by maintaining a normal body weight through physical exercise and healthy diet (Colberg et al., 2010; Mayor, 2015). Air pollution has also been proposed as an emerging global risk factor for the development of type 2 DM (Rajagopalan and Brook, 2012). Increasing evidence from epidemiological studies links long-term air pollution exposure with type 2 DM, however, the findings are not definitive. Associations of long-term $PM_{2.5}$ exposure with the development of DM were observed in Canada (Brook et al., 2013; Chen

Abbreviations: AOD, Aerosol Optical Depth; CI, Confidence Interval; DM, diabetes mellitus; ICD-9, International Classification of Diseases, 9th version; IQR, interquartile range; HR, hazard ratio; OR, odds ratio; $PM_{2.5}$, fine particulate matter with aerodynamic diameter ≤ 2.5 Microns; SEC, Surface extinction coefficients; TPU, Tertiary Planning Units

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* Corresponding author at: School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, 7 Sassoon Road, Pokfulam, Hong Kong.
E-mail address: linweit@hku.hk (L. Tian).

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et al., 2013), Denmark (Hansen et al., 2016), as well as in China (Liu et al., 2016) but not in some US cohort studies (Coogan et al., 2012; Park et al., 2015; Puett et al., 2011). Although there have systematic reviews and meta-analyses reported the statistically significant pooled estimates of association between long-term $PM_{2.5}$ exposure and diabetes (Eze et al., 2015; Wang et al., 2014), the studies included in these reviews were quite limited and the results of each individual study were diverse. In this situation where observations are conflicting, evidence from different settings, with different levels of exposure, patterns of DM and potential biases may provide clarification.

The Hong Kong Chinese elderly health service cohort was set up by the Department of Health in July 1998, with the purpose to promote understanding of aging in Hong Kong where the patterns of common chronic diseases and their determinants may differ from those in the West (Schooling et al., 2016). Hong Kong is an economically developed non-Western setting with high levels of diabetes, without corresponding levels of obesity and high levels of exposure to $PM_{2.5}$ (Schooling et al., 2016). We took advantage of this long-running cohort to assess the association of long-term residential exposure to $PM_{2.5}$ with both the prevalence and incidence of type 2 DM. Given that some previous studies reported a significant association between air pollution and DM only among women (Eze et al., 2015; Hansen et al., 2016; Krämer et al., 2010), we conducted stratified analyses by sex to explore effect modification.

2. Materials and methods

2.1. Study population

An elderly Chinese cohort of 66,820 older adults who aged 65 years or above was set up by the Elderly Health Service (EHS) of the Department of Health in Hong Kong from July 1998 to December 2001. The participants were recruited on voluntary basis. Elderly Health Centre (EHC) that located in each of the 18 districts in Hong Kong provides health assessment, using standardized and structured interviews, and comprehensive clinical examinations. Information on sociodemographics, lifestyles, and disease history was collected by doctors and nurses, as described in a previous study using the data collected by registered nurses (Schooling et al., 2016). The protocol was approved by the Institutional Review Board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster and the ethics committee of the Department of Health. This is an analysis of routinely collected data, the participants implicitly agreed to their data being used for research by using the service.

2.2. Outcome ascertainment

The prevalent cases of diabetes were identified as those with self-reported diabetes mellitus (DM) receiving regular health care at baseline in the questionnaire survey. Almost all of the DM cases in the elderly population can be assumed to be type 2 DM (Park et al., 2015). The participants without DM at baseline were followed up to ascertain incident type 2 DM. New occurrences of type 2 DM from 1998 to 2010 was obtained from hospitalization records of the Hospital Authority, which manages all 42 public hospitals in the entire territory of Hong Kong. All hospital discharges are coded using the International Classification of Diseases, Ninth Revision (ICD-9), with 250.x0 and 250.x2 (x = 0–9) for type 2 DM (Centers for Disease Control and Prevention, 2011). We identified participants who had the hospital admissions for type 2 DM during 1998 and 2010, and their date of first admission.

2.3. Exposure assessment for residential $PM_{2.5}$

Satellite-based estimates of long-term $PM_{2.5}$ exposure from 1998 to 2010 were obtained from satellite sensing calibrated against surface measurements, as previously descripted (Wong et al., 2015). Briefly, Aerosol Optical Depth (AOD), an indicator of $PM_{2.5}$ levels in the troposphere, was retrieved from remote sensing by two NASA Earth Observing System satellites (NASA, 2015). Surface extinction coefficients (SEC) obtained from AOD at 1 × 1 km resolution, controlling for humid and rainy days, were used to predict $PM_{2.5}$ (HKUST, 2015). Excluding roadside stations, Hong Kong Environmental Protection Department (EPD) provided four general stations for $PM_{2.5}$ measurement during the study period. We calculated annual mean $PM_{2.5}$ concentrations from 1998 to 2010 for each general monitoring station from hourly concentrations and then regressed on the corresponding annual mean SEC, which was the exposure model. The validity of this approach has been confirmed by cross-validation tests in previous study (Wong et al., 2015).

The residential addresses for all participants were geo-coded and linked with SEC data. Then the annual $PM_{2.5}$ exposures at geographical locations of individual participants were estimated using the same exposure model with annual SEC as the explanatory variable for each year. $PM_{2.5}$ concentrations averaged over the baseline years between 1998 and 2001 were used as the proxy of exposure to examine the association with prevalent DM, while the annual mean $PM_{2.5}$ exposure over the follow-up period (1998–2010) as a time-varying variable was used to examine the association with incident type 2 DM. About 13.3% patients in this Elderly Cohort had their residential addresses changed between 1998 and 2010. We have taken the residential movement into account in the estimation of $PM_{2.5}$ exposure by year (Qiu et al., 2017).

2.4. Other covariates

We included individual covariates of age, gender, body mass index (BMI), smoking status, alcohol drinking, exercise frequency, education level and personal monthly expenditure. Active diseases were defined as self-reported hypertension, heart diseases, COPD/asthma, or cerebrovascular accident at baseline. We also included neighborhood characteristics, including percentage of older people (aged 65+ years), percentage with tertiary education and with monthly domestic household income higher than US$ 1923, based on small area statistics (Census and Statistics Department, 2002) (197 Tertiary Planning Units (TPU)) from the census. Environmental characteristics included percentages of smokers (aged 15+) in the 18 districts of Hong Kong to indicate exposure to environmental tobacco smoke (ETS) at baseline years (Census and Statistics Department, 2011).

2.5. Statistical analysis

To estimate the association of baseline $PM_{2.5}$ with prevalence of DM (Park et al., 2015), we used logistic regression. To estimate the association of annual exposure to $PM_{2.5}$ with incidence of type 2 DM we used time-varying Cox regression (Andersen et al., 2012), with attained age as the underlying time scale, because it accounts better adjustment for potential confounding by age (Thiebaut and Benichou, 2004). Using attained age as the time scale provides the flexible control for age effect while avoiding the need to include an effect of age when considering the lifetime exposure (Griffin et al., 2013). Attained age was calculated as the age of first hospital admission for type 2 DM, age at death or age at end of follow-up on 2010-12-31.

We estimate the odds ratio (OR) and hazard ratio (HR) per interquartile range (IQR, $3.22\,\mu g/m^3$) increase of $PM_{2.5}$ concentrations in three different models, while adjusting for an increasing number of potential confounders obtained from the literature as possible common causes of $PM_{2.5}$ exposure and diabetes (Andersen et al., 2012; Chen et al., 2013). Model 1 adjusted for age and sex in logistic model, or sex and calendar year of entry in Cox model while using attained age as the underlying time scale (Stafoggia et al., 2014). Model 2 additionally adjusted for body mass index (BMI), smoking status, alcohol drinking, physical exercise, education, monthly expenses, medication taken and self-reported comorbidities including hypertension, heart diseases,