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Short-term effects of fine and coarse particles on deaths in Hong Kong elderly population: An analysis of mortality displacement[☆]

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ABSTRACT

Background: While numerous studies worldwide have evaluated the short-term associations of fine and coarse particulate matter (PM) air pollution with mortality and morbidity, these studies may be susceptible to short-term harvesting effect. We aimed to investigate the short-term association between mortality and PM with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) and those between 2.5 and 10 μm (PMc) within a month prior to death, and assess the mortality displacement by $PM_{2.5}$ and PMc among elderly population in Hong Kong.

Methods: We obtained air pollution data from January 2011 to December 2015 from Environmental Protection Department, and daily cause-specific mortality data from Census and Statistical Department of Hong Kong. We performed generalized additive distributed lag model to examine the acute, delayed and long-lasting effects of $PM_{2.5}$ and PMc within one month on mortality.

Results: We observed a statistically significant association of $PM_{2.5}$ and PMc exposure over lags 0–6 days with all natural mortality and cardio-respiratory mortality. The overall cumulative effect of $PM_{2.5}$ over 0–30 lag days was 3.44% (95% CI: 0.30–6.67%) increase in all natural mortality and 6.90% (95% CI: 0.58–13.61%) increase of circulatory mortality, which suggested the absence of mortality displacement by $PM_{2.5}$. On the other hand, no significant cumulative association with mortality was found for PMc over 0–30 lag exposure window, and thus mortality displacement by PMc cannot be ruled out. Findings remained robust in various sensitivity analyses.

Conclusions: We found adverse effect of both $PM_{2.5}$ and PMc exposure within one week prior to death. While there was no evidence of mortality displacement in the association of $PM_{2.5}$ exposure over one month prior with all natural and circulatory mortality, mortality displacement by PMc cannot be ruled out. $PM_{2.5}$ may contribute more to the longer term effect of particulate matter than PMc.

1. Introduction

The associations of fine and coarse particulate matter (PM) air pollution with mortality and morbidity have been widely discussed (Adar et al., 2014; Brunekreef and Forsberg, 2005), with consistent evidence of an acute health effect of fine particles with aerodynamic diameter ≤ 2.5 μm ($PM_{2.5}$) (Englert, 2004), and supporting evidence of an effect of coarse particles with aerodynamic diameter between 2.5 and 10 μm (PMc), especially with respiratory diseases (Adar et al., 2014; Qiu et al., 2012). While majority of the epidemiological studies on the health effects of $PM_{2.5}$ and PMc focused on short exposure period, i.e., from the day of disease onset/death to previous few days (Meister et al., 2012; Qiu et al., 2012; Samoli et al., 2013; Zanobetti and Schwartz, 2009), these studies may be susceptible to potential short-term harvesting effect (Schwartz, 2000a). Harvesting effect, also known as mortality displacement, of air pollution-related deaths is a phenomenon where air pollution principally affects frail population by advancing their deaths by a number of days or weeks because of their already poor health conditions, and the initial increase in mortality rate is then

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Abbreviations: DLM, distributed lag model; GAM, generalized additive model; ICD-10, international statistical classification of diseases, 10th revision; IQR, interquartile range; PM_{10}, particulate matter with an aerodynamic diameter less than 10 μm; $PM_{2.5}$, fine particles with an aerodynamic diameter less than 2.5 μm; PMc, coarse particles with an aerodynamic diameter between 2.5 and 10 μm.

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followed by a period with a lower-than-expected mortality rate (Schwartz, 2001; Zeger et al., 1999). The presence of harvesting effect could limit the public health significance of air pollution.

A combination of *generalized additive model* and *distributed lag model* has been suggested to model the relationship between lagged exposure of multiple days (e.g., lag 0–30 days), and subsequently to quantify the mortality displacement or harvesting effect effectively in air pollution epidemiological studies (Schwartz, 2000a; Zanobetti et al., 2000). However, there remains limited research on the harvesting effect and distributed lag effects of PM. In 2000, Schwartz examined various distributed lag of $PM_{2.5}$ on mortality using seasonal-trend decomposition algorithm, and found evidence of harvesting effects on different time scales (Schwartz, 2000b). Costa et al. showed evidence of mortality displacement within 30 days for nonaccidental and circulatory deaths using distributed lag model in elderly residents of São Paulo (Costa et al., 2017). To our knowledge, no studies have assessed the harvesting effect and distributed lag effects of $PM_{2.5}$ and PMc in the same setting.

Hong Kong is an ideal place to study the health effects of short-term exposure to $PM_{2.5}$ and PMc, because of its readily available measures of hourly PM_{10} and $PM_{2.5}$ concentrations monitored simultaneously in every monitoring station dispersed across the territory since January 2011. Our previous studies have demonstrated acute effects of both $PM_{2.5}$ and PMc within one week on cardio-pulmonary diseases in Hong Kong (Qiu et al., 2014, 2013, 2012). The current study built upon this observation by quantifying mortality displacement and examining the short-term association between cause-specific mortality and $PM_{2.5}$ and PMc exposure in a month prior to death, using the package ‘dlnm’ developed within the statistical environment R (Gasparrini et al., 2010). Given that the aging population in Hong Kong is increasing [from 12% in 2006 to 16% in 2016 (http://www.censtatd.gov.hk)], and because they are most vulnerable to air pollution, we studied the mortality displacement in Hong Kong elderly population aged 65 or above.

2. Materials and methods

2.1. Data collection

We obtained pairwise hourly measures of $PM_{2.5}$ and PM_{10} concentrations collected between January 1, 2011 to December 31, 2015 at 14 general air quality monitoring stations maintained by the Hong Kong Environmental Protection Department (EPD) (HKEPD, 2016). Missing data accounted for only 3.1% and 10.7% of PM_{10} and $PM_{2.5}$ measurements, respectively, and thus data were not imputed. Hourly PMc concentrations were calculated by subtracting $PM_{2.5}$ from PM_{10} measurements for each station. We then computed daily 24-hr mean concentrations of $PM_{2.5}$ and PMc if at least 18 of 24 hourly measurements were available for each monitor. Air pollution measurements from one general station on a remote island and three roadside stations were excluded, and the final analysis included daily measurements of $PM_{2.5}$ and PMc from 10 general monitoring stations that represent the citywide background air pollution level and general population's daily exposure (Qiu et al., 2014). Meteorological data of daily mean temperature and relative humidity were collected from Hong Kong Observatory for the same study period.

Mortality data among elderly Hong Kong residents aged 65 or above between 2011 and 2015 were obtained from Hong Kong Census and Statistical Department. The causes of death were identified according to the WHO *International Statistical Classification of Diseases, 10*th *Revision* (ICD-10). Daily counts of mortality from all natural causes (ICD-10: A00-R99), circulatory diseases (ICD-10: I00–I99) and respiratory diseases (ICD-10: J00-J99) were computed and subsequently linked to air pollution and meteorological data. Ethics approval and consent from individual subjects were not required, as no individualized data but aggregated data were used in this study.

2.2. Statistical modelling

We used time series Poisson model to examine the association between PM in different size fractions and daily mortality. Generalized additive regression model (GAM) integrated with distributed lag model (DLM) were used to investigate the potential mortality displacement in the association (Zanobetti et al., 2000). We used smoothing spline function, *s(.)*, to filter out long-term trend and seasonality in time series of daily mortality as well as daily mean temperature and relative humidity (Peng et al., 2006; Schwartz et al., 1996). Based on previous studies we followed a priori model specifications and the degree of freedom (*df*) for the time trend and other time-varying covariates, in order to reduce the problems coming from multiple testing and model selection strategies (Peng et al., 2006; Qiu et al., 2012). Time trend with a *df* of 7 per year, temperature of the current day ($Temp_0$) and the mean of previous 3 days ($Temp_{1\text{-}3}$) with a *df* of 6, and relative humidity of the current day ($Humid_0$) with a *df* of 3 were used.The day of the week (*DOW*) and public holidays (*Holiday*) were included as dummy variables to the model (Qiu et al., 2012).

Briefly, a core model was set up to remove the long-term trend, seasonality, with adjustment for time varying covariates as follows:

$$\log[E(Y)] = \alpha + s(t, df = 7/year \times 5years) + s(Temp_0, df{=}6) + s(Temp_{1\text{-}3}, df = 6) + s(Humid_0, df = 3) + \beta_{1,i}\, DOW + \beta_2\, Holiday \quad (1)$$

Here E(Y) is the expected daily counts of mortality on day t; s(.) is the smoothing spline function for nonlinear covariates. We observed no discernible patterns and autocorrelation in the model residuals assessed by residual plot and partial autocorrelation function (PACF) for all three mortality outcomes (Costa et al., 2017). The standardized deviance residuals shown in the Q-Q plot were also normal (Fig. 1), which suggested that all unmeasured time-varying confounding in the daily variations of mortality series had been controlled for. Once the model was correctly specified, the terms of PM2.5 or PMc were included into the model to estimate their single-pollutant association with daily cause-specific mortality.

Distributed lag model (DLM), which was integrated in the GAM as *cross-basis* function to account for the potential distributed and lagged effect of pollution on mortality flexibly, was used to estimate the short-term health effects associated with $PM_{2.5}$ or PMc exposure in the 30-days prior to mortality (Gasparrini et al., 2010). In the primary analysis, second-degree (quadratic) polynomials was used to constrain the smooth shape of the effects of distributed lags ≤ 30 days for daily mortality (Costa et al., 2017). We calculated the cumulative effect of $PM_{2.5}$ or PMc distributed over 0–30 lag days to estimate the overall effect lasting for one month, as well as the cumulative effects of $PM_{2.5}$ or PMc over the different lag periods: 0–6 days, 7–13 days, and 14–30 days, representing the acute, delayed and long-lasting effects, respectively (Qiu et al., 2016). Single-lag effects of $PM_{2.5}$ and PMc over 30 days exposure on daily mortality were shown, as well as the cumulative effects of $PM_{2.5}$ and PMc for the investigation of mortality displacement (Costa et al., 2017; Gasparrini, 2011). As described in detail by Schwartz and Zanobetti, the cumulative effects of PM on daily mortality should reduce to zero, and the confidence intervals for the cumulative risks should include zero in the presence of mortality displacement (Schwartz, 2000a; Zanobetti et al., 2000).