International Journal of Cardiology 168 (2013) 500–505

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

Cool and dry weather enhances the effects of air pollution on emergency IHD hospital admissions

Hong Qiu, Ignatius Tak-sun Yu *, Xiaorong Wang, Linwei Tian, Lap Ah Tse, Tze Wai Wong

School of Public Health and Primary Care, The Chinese University of Hong Kong, Hong Kong, China

ARTICLE INFO

Article history:
Received 27 June 2012
Accepted 26 September 2012
Available online 15 October 2012

Keywords:
Air pollution
Emergency hospital admissions
Ischemic heart disease
Modification
Weather factors

ABSTRACT

Background: Associations between ambient pollution and cardiovascular morbidity including ischemic heart disease (IHD) have been confirmed. Weather factors such as temperature, season and relative humidity (RH) may modify the effects of pollution. We conducted this study to examine the effects of air pollution on emergency IHD hospital admissions varied across seasons and RH levels, and to explore the possible joint modification of weather factors on pollution effects.

Methods: Daily time series of air pollution concentrations, mean temperature and RH were collected from IHD hospital admissions from 1998 to 2007 in Hong Kong. We used generalized additive Poisson models with interaction term to estimate the pollution effects varied across seasons and RH levels, after adjusting for time trends, weather conditions, and influenza outbreaks.

Results: An increase in the detrimental effects of air pollution in cool season and on low humidity days was observed. In the cool and dry season, a 10 μg/m^3 increment of lag_{03} exposure was associated with an increase of emergency IHD admissions by 1.82% (95% CI: 1.24–2.40%), 3.89% (95% CI: 3.08–4.70%), and 2.19% (95% CI: 1.33–3.06%) for particles with an aerodynamic diameter less than 10 μm (PM_{10}), nitrogen dioxide (NO_2), and ozone (O_3), respectively. The effects of pollutants decreased greatly and lost statistical significance in the warm and humid season.

Conclusions: We found season and RH jointly modified the associations between ambient pollution and IHD admissions, resulting in increased IHD admissions in the cool and dry season and reduced admissions in the warm and humid season.

1. Introduction

Ischemic heart disease (IHD) is one of the most common health threats to the adult population in Hong Kong and in many other countries. It is a condition in which heart muscle is damaged or works inefficiently because of an absence or relative deficiency of its blood supply; most often caused by atherosclerosis which induces angina pectoris, acute myocardial infarction, chronic IHD and sudden death. In the past decade, the adverse effects of air pollution on the morbidity rate from cardiovascular disease have been confirmed worldwide [1–6]. The associations between pollution and more specific outcomes of cardiovascular diseases including IHD have also been well documented [7,8].

Some studies identified the effects of ambient temperature and relative humidity on the incidence of heart disease [9,10]. It was suggested that both hot and cold weather had detrimental effects on the short-term risk of all heart disease including myocardial infarction, but there was no evidence to support the effect of humidity. Researchers have examined the different effects of pollutants on cardiovascular diseases by temperature or season, but the findings were inconstant. Some studies found higher pollutant effects in winter [11] or an increasing effect with decreasing temperature [12], while Ren et al. found that a higher temperature enhanced the effect of particles [13] and ozone [14]. These studies showed that season or temperature modified the effect of pollutant on heart diseases. A study of Air Pollution and Health: European Approach 2 (APHEA2) compared the association of daily SO_2 levels with hospital admissions for cardiovascular diseases in seven European cities and explained the heterogeneity of SO_2 effects by the different average levels of humidity of each city [1], which were greater in cities with lower levels of humidity. In another two studies from the APHEA2 project conducted in 29 European cities, temperature and humidity were identified as effect modifiers for the effects of ambient particles on total mortality [15,16]. The effect parameters estimated were larger in warmer and drier countries.

Abbreviations: ERR, excess relative risk; ICD-9, international statistical classification of diseases, 9th revision; IHD, ischemic heart disease; lag_{0n}, n-day moving average of current day to previous n days; NO_2, nitrogen dioxide; O_3, ozone; PACF, partial autocorrelation function; PM_{10}, particles with an aerodynamic diameter less than 10 μm; RH, relative humidity; SO_2, sulfur dioxide.

* Corresponding author at: School of Public Health and Primary Care, The Chinese University of Hong Kong, 4/F School of Public Health and Primary Care, Prince of Wales Hospital, Shatin, N.T., Hong Kong, China. Tel.: +852 2252 8773; fax: +852 2606 3500.

E-mail address: iyu@cuhk.edu.hk (I.T. Yu).

0167-5273/$ – see front matter © 2012 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijcard.2012.09.199

In the present study, we aimed to examine if the effects of air pollutants on emergency IHD hospital admissions varied across seasons and RH levels in Hong Kong, by adding interaction terms between air pollutants and season or RH levels [17–20], and to explore the possible joint modification of weather factors on the effects of air pollution.

2. Materials and methods

2.1. Air pollutant and meteorological data

Air pollution concentrations from January 1998 to December 2007 were obtained from the Environmental Protection Department. Hourly concentrations of four air pollutants (PM_{10}, NO_2, O_3, and SO_2) were monitored in 14 monitoring stations located in different districts of Hong Kong. Three roadside stations and one station on a remote island were excluded, leaving 10 general stations to generate daily mean air pollution concentrations. We calculated daily 24-h mean concentrations of PM_{10}, NO_2, SO_2 and 8-h (10:00–18:00) mean concentration of O_3 for each monitoring station if at least 75% of hourly concentrations of each pollutant were available, and then averaged them across the 10 stations to denote the pollution concentrations in Hong Kong [21]. The daily mean temperature and relative humidity for the same period were obtained from the Hong Kong Observatory.

2.2. Hospital admission data

A daily count of emergency hospital admissions for ischemic heart disease (IHD, ICD-9: 410–414) as the principal diagnosis from 1998 to 2007 was obtained from the Hospital Authority Corporate Data Warehouse. The records of admission were taken from the publicly funded hospitals providing 24 hour accident and emergency services and covering 90% of hospital beds in Hong Kong for local residents [22]. Daily admissions for influenza (ICD9: 487.0–487.8) were used to indentify influenza epidemics, which were then treated as a potential confounder in the data analysis [19,23].

2.3. Statistical methods

This is a time series study. The daily number of emergency hospital admissions for IHD was considered as the outcome variable and the daily mean concentrations of four air pollutants (PM_{10}, NO_2, O_3 and SO_2) were analyzed as the main exposure. Generalized additive Poisson models were used to fit the relationship between the daily air pollution concentrations and the emergency hospital admissions for IHD [24]. We used the smoothing spline, $s(.)$, to filter out seasonal patterns and long-term trends in daily hospitalizations, as well as the daily mean temperature and relative humidity [25]. We also included an adjustment for the day of the week and dichotomous variables such as public holidays and influenza outbreaks.

We followed previous studies to select a priori the model specification and the degree of freedom (*df*) for the time trend and other meteorological variables [4,11,26]. We used a *df* of 8 per year for the time trend, a *df* of 6 for the mean temperature of the current day ($Temp_0$) and the previous 3 days' moving average ($Temp_{1-3}$) and a *df* of 3 for the current day RH ($Humid_0$) and the previous 3 days' moving average ($Humid_{1-3}$). We included the day of the week (*DOW*) and public holidays (*Holiday*) in the model as dummy variables [27]. To adjust for the confounder effect of an influenza epidemic on emergency hospital admissions, we entered a dummy variable for the weeks with a number of influenza hospital admissions exceeding the 75 percentile in a year into the core model [20].

Briefly, we set up a core model to remove the long term trends, seasonal variations and adjust for time varying confounders as follows:

$$\log(E(Y)) = a + s(t, df = 8/year \times no.of\ years) + s(Temp_0, df = 6) + s(Temp_{1-3}, df = 6) + s(Humid_0, df = 3) + s(Humid_{1-3}, df = 3) + \beta_1 DOW + \beta_2 Holiday + \beta_3 influenza. \quad (1)$$

Here $E(Y)$ means the expected daily emergency IHD hospital admission counts on day t; $s(.)$ is the smoothing spline function for nonlinear variables. We examined the residuals of the core model to check whether there were discernible patterns and autocorrelation by means of residual plot and partial autocorrelation function (PACF) plot. The PACF of residuals of the core model (1) was smaller than 0.1 for all the lags, which meant no serial correlation in the residuals and sufficient confounder control [28,29]. No discernible patterns and no autocorrelation in the residuals are the criteria for an adequate core model set up which is intended to remove all potential confounders in the daily variations of health outcome. The linear effect of each pollutant was then estimated for the same day and up to three days before the outcome (lag_0, lag_1, lag_2 and lag_3) and moving averages of up to 3 days (lag_{01}, lag_{02} and lag_{03}). The greatest effects of both single day lag and multi-day lag for each pollutant were used in further analysis.

We created a binary variable for the season, with 0 for the warm season (from May to October) and 1 for the cool season (November to April). Another binary variable (*humid01*) was coded to denote the daily humidity levels, with 0 for low humidity days (RH<80%) and 1 for high humidity days (RH>=80%). The cutoff point for RH was chosen around the median (79% in HK) on considering the statistical power. We then added the product term between pollutant concentrations (continuous variable) and the season or RH level (binary variable) into the core model to test the possible interaction between pollution and meteorological factors. If the p value for the product term was statistically significant, we estimated the pollution effects across seasons or RH levels, as some researchers did in previous studies [17–19]. The equations were as follows:

$$\log(E(Y)) = \beta_1 pollutant + \beta_2 season + \beta_3 pollutant \times season + COVs \quad (2)$$

$$\log(E(Y)) = \beta_1 pollutant + \beta_2 humid01 + \beta_3 pollutant \times humid01 + COVs. \quad (3)$$

COVs were all time varying confounders identified in the core model (1). In model (2), β_1 was the pollutant effect in the warm season whose confidence interval could be estimated directly through the model fit, and $(\beta_1+\beta_3)$ was the pollutant effect in the cool season whose confidence interval could be estimated by the method that incorporated the coefficient of the pollutant and the covariance of the pollutant and the interaction term [17,30]. In model (3), the pollutant effect on low and high humidity days was denoted by β_1 and $(\beta_1+\beta_3)$ respectively.

Similarly, a categorical variable with four categories (*season_humidity*) was also coded to denote the four combinations of season and RH. It divided the whole data into four discontinuous periods that were: warm season with low humidity days (warm and dry season), warm season with high humidity days (warm and humid season), cool season with low humidity days (cool and dry season) and cool season with high humidity days (cool and humid season). We then added the product term of the pollutant concentrations (continuous variable) and *season_humidity* (categorical variable, set as dummy variables) into the core model to test the possible interaction between pollution and the four seasons. The varied pollution effects across four different seasons were estimated to explore the possible joint modification of season and RH on the effects of pollution.

The results were expressed in terms of the percentage increase (Excess Relative Risk, ERR (%)) in emergency IHD hospital admissions for a 10 $\mu g/m^3$ increment of pollutant concentrations, and respective 95% confidence intervals (CI). All analyses were conducted in the statistical environment R2.11.1 (R Development Core Team, 2011: http://www.r-project.org).

Table 1
Distribution of emergency IHD hospital admissions, air pollution concentrations and meteorological factors in Hong Kong, 1998–2007.[a]

	Whole period (n = 3652)	Warm season[b] (n = 1840)	Cool season[c] (n = 1812)	Low humid days[d] (n = 1888)	High humid days[e] (n = 1764)
Emergency hospital admissions (counts/day)					
Diseases of circulatory system	153.8 (23.4)	143.4 (17.7)	164.3 (23.8)	155.1 (23.8)	152.3 (22.9)
Ischemic heart diseases	30.2 (6.6)	28.6 (6.1)	31.8 (6.7)	30.5 (6.6)	29.8 (6.6)
Air pollutants ($\mu g/m^3$)					
PM_{10}	52.8 (26.9)	43.0 (24.0)	62.8 (26.0)	62.8 (28.6)	42.1 (20.1)
NO_2	58.0 (20.5)	50.1 (19.2)	66.0 (18.6)	63.0 (22.4)	52.7 (16.8)
O_3	39.8 (24.3)	40.9 (28.0)	38.8 (19.8)	51.1 (25.5)	27.7 (15.6)
SO_2	19.5 (13.2)	20.0 (14.6)	19.0 (11.5)	21.4 (13.8)	17.5 (12.1)
Meteorological factors					
Temperature (°C)	23.6 (4.9)	27.6 (1.9)	19.6 (3.6)	23.3 (5.4)	23.9 (4.4)
Relative humidity (%)	78.1 (10.0)	79.4 (8.1)	76.7 (11.5)	70.9 (8.4)	85.7 (4.4)

[a] Data were expressed as mean (SD); Abbreviation: n, number of days for analysis.
[b] From May to October.
[c] From November to April.
[d] Days with relative humidity <80%.
[e] Days with relative humidity >=80%.