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A case-crossover analysis of Asian dust storms and mortality in the downwind areas using 14-year data in Taipei ☆

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ABSTRACT

This study aims to assess the association between Asian dust storms (ADS) and daily mortality in Taipei, Taiwan. A time-stratified case-crossover design was used to investigate the effects of ADS on mortality. Odds ratios (ORs) of total non-accidental (ICD-9 <800), cardiovascular (ICD-9 390–459, 785), and respiratory deaths (ICD-9 460–519, 786) were estimated for residents in Taipei metropolis over a 14-year study period between 1994 and 2007 by conditional logistic regression. Air pollution levels and temperature data were recorded by a network of 16 monitoring stations spreading around Taipei. Compared with reference days, particulate matter with aerodynamic diameter less than 10 and 2.5 μm (PM_{10} and $PM_{2.5}$) increased statistically significantly by 24.2 μg/m^3 and 7.9 μg/m^3 per dust day, respectively. There were also statistically significant increases in sulfur dioxide (SO_2) and ozone (O_3) but decreases in temperature during ADS. Excess deaths were increased significantly for residents of all ages for total non-accidental deaths, with OR = 1.019 (95% CI 1.003–1.035), and also for residents above 65 years old, with OR = 1.025 (95% CI 1.006–1.044) for total non-accidental deaths and OR = 1.045 (95% CI 1.0011–1.081) for cardiovascular deaths, respectively but not for respiratory deaths during ADS. Such increases in mortality remained statistically significant in the regression models with either SO_2 or O_3. This study found that acute exposure to long-range transported Asian dust can increase the number of non-accidental and cardiovascular deaths for people of all ages and the elderly population aged above 65 on the dust storm days in Taipei, Taiwan. Further studies are still needed to find out whether mass concentrations alone or specific components in PM are responsible for excess cardiovascular deaths by ADS.

1. Introduction

Asian dust storms (ADS) occur in winter and spring (November to May), especially in March to May, and mainly originate in the Gobi and Takla Makan deserts in Mongolia and western China. They can move eastward to China, Japan, Korea, Taiwan, and sometimes to northern Pacific Ocean areas (Guo et al., 2004; Han et al., 2008; Hwang et al., 2008; Liu et al., 2006; Ma et al., 2005). Particulate matter (PM) levels, especially particulate matter with aerodynamic diameters less than 10 μm (PM_{10}), have been recorded above 500 μg/m^3 and sometimes over 1000 μg/m^3 during several ADS in many downwind area cities (Kim et al., 2010; Song et al., 2006). A recent ADS occurrence in East Asia during 21–23 March 2010 caused several Asian cities to experience the worst air quality in recent years. The Shanghai Environmental Protection Bureau recorded a 24-hour average air pollution index (API) of above 500 on 21 March (Shanghai Environmental Protection Bureau, 2010); the Environmental Protection Department of Hong Kong recorded peak hourly API above 500 on 22–23 March (Hong Kong Environmental Protection Department, 2010); and the Taiwan Environmental Protection Administration reported peak hourly PM_{10} concentrations at 1724 μg/m^3 and 24-hour average PM_{10} concentration of 703 μg/m^3 on 21 March in Taipei (Taiwan Environmental Protection Administration, 2010).

The health effect of ADS has become a major concern in recent years. Both animal and human studies have investigated potential adverse effects corresponding to the PM pollution in ADS. Studies on experimental rats have shown statistically significant toxicological effects of PM on inflammation, heart rates and blood pressure during dust events in Taiwan (Chang et al., 2005, 2007; Lei et al., 2004). Epidemiological studies in Taiwan also suggested that ADS increased emergency room visits for ischemic heart diseases, cerebrovascular

Abbreviations: ADS, Asian dust storms; PM, particulate matter; API, air pollution index; PM_{10}, particulate matter with aerodynamic diameters less than 10 μm; TEPA, Taiwan Environmental Protection Administration; NOAA, U.S. National Ocean and Atmospheric Administration; NCEP, National Centers for Environmental Prediction; $PM_{2.5}$, particulate matter with aerodynamic diameter less than 2.5 μm; NO_2, nitrogen dioxide; SO_2, sulfur dioxide; CO, carbon monoxide; O_3, ozone; ICD-9, International Classification of Diseases, 9th revision; OR, odds ratio; CI, confidence interval; EC, elemental carbon; OC, organic carbon.

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diseases and chronic obstructive pulmonary diseases (Chan et al., 2008), as well as daily hospital admissions for intracerebral hemorrhagic strokes (Yang et al., 2005). However, the effect of ADS on mortality is still unclear. By using mortality data as health outcomes, three studies before have found insignificant impacts of ADS on mortality in Korea and Taiwan, even though PM_{10} concentrations during dust storm days were significantly higher than non-dust storm days. Lee et al. found no increase in total non-accidental deaths over 63 dust storms days during 2000–2004 in Seoul, Korea (Lee et al., 2007) and Chen et al. did not find increases in cardiovascular and respiratory mortality over 39 dust storms days during 1995–2000 in Taipei, Taiwan (Chen et al., 2004b). One common limitation of these studies was their relatively short observation times, which were only four to 6 years. This may have resulted in the constraint of the statistical power to detect a statistically significant effect on the rare events associated with dust storms.

This study aims to assess the association between ADS and daily mortality of residents in Taipei metropolis, Taiwan, by applying a case-crossover design to a longer observational period of 14 years between 1994 and 2007.

2. Materials and methods

2.1. Definition of ADS in Taipei metropolis

The Taipei metropolis is located in northern Taiwan and had a population of 5.91–6.43 million between 1994 and 2007 in an area of 2324 km^2. It is located approximately 4000 km southeast of the origins of dust storms, and is one of the major downwind areas of ADS. The detailed definition of ADS in Taipei has been well described in our previous study (Chan et al., 2008). In brief, Taiwan Environmental Protection Administration (TEPA) defines an “Asian dust event” through several procedures. First of all, daily weather reports in the east-Asian region during the dust storm season used to confirm whether there are dust storms occurring in China's northwest, northern, and Mongolian regions. Then, information from China's dust storm web page is used to confirm the dust storms' occurrence in China and Mongolia. Using the data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite, TEPA analyzes graphical data of aerosol and optical depth to triangulate the position of the dust storm. Two background air monitoring stations, the coastal monitoring station of Wanli and the Yang Ming Shan National Park monitoring station are used to detect whether there are statistically significant increases in hourly concentrations of PM_{10} to above 100 $\mu g/m^3$ from both station's normal range of 10–50 $\mu g/m^3$ year round. In addition, the averaged hourly PM_{10} concentration of 3 randomly selected stations among all 16 TEPA-operated air monitoring stations within the Taipei metropolitan area must be higher than 100 mg/m^3 in order to constitute a dust storm (Liu et al., 2006). By using yellow dust ground observation, forward satellite tracking and backward trajectory analysis of air mass movements, and ambient particulate measurements described above, there are 380 such ADS between 1994 and 2007 recorded by TEPA, which are used for further statistical analysis in this study. The other 4733 days (5113 days − 380 days), which are not affected by ADS, are defined as “non-ADS days”.

2.2. Air pollution and meteorological data

The air quality and meteorological conditions were measured by 16 TEPA-operated urban air monitoring stations that are spread around the Taipei metropolis. In addition to PM_{10}, TEPA-operated urban air monitoring stations also continuously measured hourly data of particulate matter with aerodynamic diameter less than 2.5 μm ($PM_{2.5}$), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3) concentrations, and temperature since 1994. The completeness of hourly data in these monitoring stations was above 96% for all pollutants during 1994–2007. For further statistical analyses, daily air quality data were summarized by 24-h arithmetic averages of temperature, $PM_{2.5}$, PM_{10}, NO_2, and SO_2 concentrations, and maximum values of 8-hour CO concentrations and 1-hour O_3 concentrations for each monitoring station. Daily measurements from these multiple monitors were averaged to generate an overall exposure estimate for the population in Taipei.

2.3. Mortality data

Mortality data covering all deaths of Taipei residents reported in Taipei metropolis between 1 January 1994 and 31 December 2007 were obtained from the Department of Health. Detailed demographic information, including gender, date of birth, date-, cause- and place of death, and residential district were recorded for each death. Deaths from accidental causes [International Classification of Diseases, 9th revision (ICD-9), codes ≥ 800] were excluded, as well as all deaths that occurred outside of the defined study area. The deaths were analyzed as a total, by age (<65 years and ≥ 65 years), by gender, and by principal underlying cause of death [cardiovascular diseases (ICD-9 390–459, 785) and respiratory diseases (ICD-9 460–519, 786)].

2.4. Statistical analysis

A time-stratified case-crossover design was used to analyze the associations between ADS and mortality for all Taipei residents in this study (Janes et al., 2005). The case-crossover study design was originally proposed to assess the effect of transient exposures on the risk of acute illness events (Maclure, 1991). It has been recently applied to investigate acute effects of air pollution in several epidemiological studies (Neas et al., 1999; Schwartz, 2004; Zanobetti et al., 2004; Zeka et al., 2005). The case-crossover design is a similar concept to a case–control for study but can better control all measured and unmeasured time-invariant confounders because each case serves as its own control. The mortality data of every day of the fourteen-year study period were used as index days in our time-stratified approach. Reference days were selected for the days that fell on the same day of the week, month and year as the index days. Odds ratios (ORs) and 95% confidence intervals (CI) were derived by using conditional logistic regression models with each subject's ID considered as a stratum variable. In the basic models, the exposure effects of ADS were investigated for exposure in ADS days (lag 0), and 1 day after ADS (lag 1), adjusted for temperature on the day of death and the day before death. A dummy variable (0 = days without ADS, 1 = ADS days) was used to represent Asian dust days and the next days after ADS. Because temperature may be non-linearly related to daily deaths, natural cubic splines were used to model these relations. The spline used three degrees of freedom each. Single-pollutant models were further developed by adding PM_{10}, $PM_{2.5}$, SO_2, and O_3 separately to basic models in order to study co-pollutant effects on dust storm days. Statistical analyses were performed with SAS version 9.1 (SAS Institute, Cary, NC).

3. Results

A total of 332,751 non-accidental deaths stratified by cause-of-death, age and gender were recorded in Taipei metropolis during 1994–2007 (Table 1). The daily trend of averaging PM_{10} concentrations calculated by 24-h arithmetic averages of measurement made at 16 TEPA-operated urban air monitoring stations in Taipei during 1994–2007 is shown in Fig. 1, which shows that the dates of peak PM_{10} levels usually coincided with the 380 ADS days in Taipei over the 14-year study period. The PM_{10} levels usually increased and decreased steeply in 1 day before and after the dust storm days. The highest daily PM_{10} level among the 380 dust storm days in Taipei