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Long-term exposure to high particulate matter pollution and cardiovascular mortality: A 12-year cohort study in four cities in northern China

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ABSTRACT

Epidemiologic studies have demonstrated that long-term exposure to relatively low levels of particulate air pollution is associated with adverse cardiovascular outcomes in Europe and North America. However, few studies have assessed the association with high level air pollutants. We aimed to assess the cardiovascular effects of long-term exposure to high level concentrations of inhalable particulate and to identify the characteristics of the Chinese population that are susceptible to the health effects. A retrospective cohort, containing 39,054 subjects from four cities in northern China, was followed for mortality of all cause and specific cardiovascular diseases from 1998 to 2009. Information on concentrations of PM_{10} (particulate matter < 10 μm in aerodynamic diameter) was collected from the local Environmental Monitoring Centers. The estimated exposure for the study participants was the mean concentration of PM_{10} over their surviving years during the cohort period. Relative risk values were obtained using Cox proportional hazards regression models after adjusting for potential confounding factors. For each 10 μg/m^3 increase in PM_{10}, the relative risk ratios (RRs) of all-cause mortality, cardiovascular disease mortality, ischemic heart disease mortality, heart failure disease mortality, and cerebrovascular disease mortality were 1.24 (95% CI, 1.22–1.27), 1.23 (95% CI, 1.19–1.26), 1.37 (95% CI, 1.28–1.47), 1.11(95% CI, 1.05–1.17), and 1.23(95% CI:1.18–1.28), respectively. Results from stratified analyses suggest that the effects of PM_{10} on cardiovascular mortality were more pronounced in males, smokers and people with a higher socioeconomic status. Long-term exposure to PM_{10} increases mortality from cardiovascular disease, especially from ischemic heart disease and this association seemed to be modified by other factors. Further research that focuses on exploring dose–response relationship and inter-population comparisons is warranted.

1. Introduction

Epidemiologic studies have demonstrated that particulate air pollution is associated with many adverse health outcomes, including mortality and morbidity from heart and lung diseases and impaired lung function (Brunekreef and Holgate, 2002). Since the early 1990s, mounting evidence has linked long-term exposure to air pollution with the risk of cardiovascular mortality (Brook and Rajagopalan, 2010; Pope et al., 1995; Dockery et al., 1993; Filleul et al., 2005; Heinrich et al., 2013; Krewski et al., 2009; Miller et al., 2007; Nishiwaki et al., 2013; Pope, 2003). However, most of these studies were conducted in areas with relatively low levels of air pollution. For example, the annual average concentration of inhalable particles (PM_{10}) was 28.8 (SD: 5.9) μg/m^3 in Abbey et al. (1999) in the United States and 22.6 μg/m^3 in Zemek et al. (2010) in Canada. Likewise, similar level of air pollution was also investigated in some European studies (Raaschou-Nielsen et al., 2013). In contrast, according to the China Ministry of Environmental Protection,

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the annual average concentrations in 113 major Chinese cities in 2009 were 87 μg/m^3 for PM_{10} (SEPA, 2010).

Although several health studies have examined the effects of higher concentrations of particulate air pollution on all-cause and cardiopulmonary mortality, hospitalizations and morbidity, most of these were either time-series, case-crossover, or short-term studies (Kan et al., 2008; Venners et al., 2003; Wong et al., 2008; Xu et al., 2000). Long term large population-based cohort studies are able to provide information in years of life lost, pollution's effects on long-term mortality and morbidity, and the role of pollution in both initiation and progression of chronic disease (Kunzli et al., 2001). Yet, few cohort studies have been conducted to demonstrate the associations between higher concentrations of air pollution and cardiovascular and cerebrovascular mortality (Cao et al., 2011; Zhang et al., 2011). Uncertainty still remains regarding the magnitude of these associations, particularly with long-term exposure to higher concentrations of PM_{10}. Further, little is known regarding whether the effect of PM_{10} is modified by other factors.

In the past three decades, China has seen both rapid economic development and the resultant deteriorating environmental pollution. In fact, China is now experiencing one of the most serious air pollution problems in the world. In the present study, we reported a large population-based cohort study of 39,054 subjects from four cities in northern China and examined the associations between high particulate air pollution levels measured by PM_{10} and all-cause and cardiovascular mortality. We further explored how other personal and socio-demographic factors may modify the health effects of PM_{10} in the study population.

2. Methods

2.1. Study area and population

China has great regional variations in industrial activities and economic development. The northern part of China is traditionally known for its heavy and energy industries, such as steel, coal, and mining. Despite intra-regional variations, in general, air quality was worse in northern cities than that in southern cities (SEPA, 2006).

The study population was from four cities in northern China: Tianjin, Shenyang, Taiyuan and Rizhao. These cities cover the full range of particulate air pollution levels in northern China (Fig. 1). Tianjin (longitude: 116°43′ to 118°04′; latitude: 38°34′ to 40°15′), comprising an area of 11917.3 km^2, lies southeast of Beijing with a population of 12.3 million in 2009. As one of the first cities with heavy industry in China, Tianjin consumes the majority of energy deriving from the combustion of coal. Shenyang (longitude: 122°25′ to 123°48′; latitude: 41°11′ to 43°2′) has a total area of 13,308 km^2 and a population of 7.9 million as of 2009. The major industries in Shenyang include steel manufacturing, nonferrous metals, machinery, chemical- and coke-related industries and electric power generation. Taiyuan (longitude: 110°30′ to 113°09′; latitude: 37°27′ to 38°25′) is the capital of Shanxi province, which is the largest coal-producing area in China. It is located on the eastern edge of the Loess Plateau, and the altitude of the residential area is 800 m above the mean sea level. The population was 3.5 million in 2009. Rizhao (longitude: 118°25′ to 119°39′; latitude: 35°04′ to 36°04′), located on the west coast of the Yellow China Sea, is an emerging coastal city. Its population was 2.7 million in 2009.

According to the design, our cohort included 10 thousand participants from each study site. The numbers of environmental monitor stations in each city was largely proportional to its geographical and population size and varied from 1 (Rizhao, the smallest city) to 7 (Tianjin, the largest city). Within a radius of 1 km from the monitoring stations, we randomly selected small neighborhoods, which were either apartment buildings or street blocks. Specifically, within the defined area around each environmental monitoring station, small neighborhoods were first numbered to form a sampling frame, from which random samples were drawn until a desired sample size was met. Approximately, each neighborhood has 500 to 700 households. To be eligible for this study, an individual had to be born before January 1st, 1975, and would have resided in the defined area for at least 10 years since January 1st, 1998.

The ethical committee of the coordinating center of Tianjin Medical University approved the study. Informed consent was obtained from all participants. There were a total of 48,114 people at the beginning of the study cohort. Because of budget constraints, we did not contact individual participants but only collected address, years of residence at present location, sex, age and ethnicity from local neighborhood offices

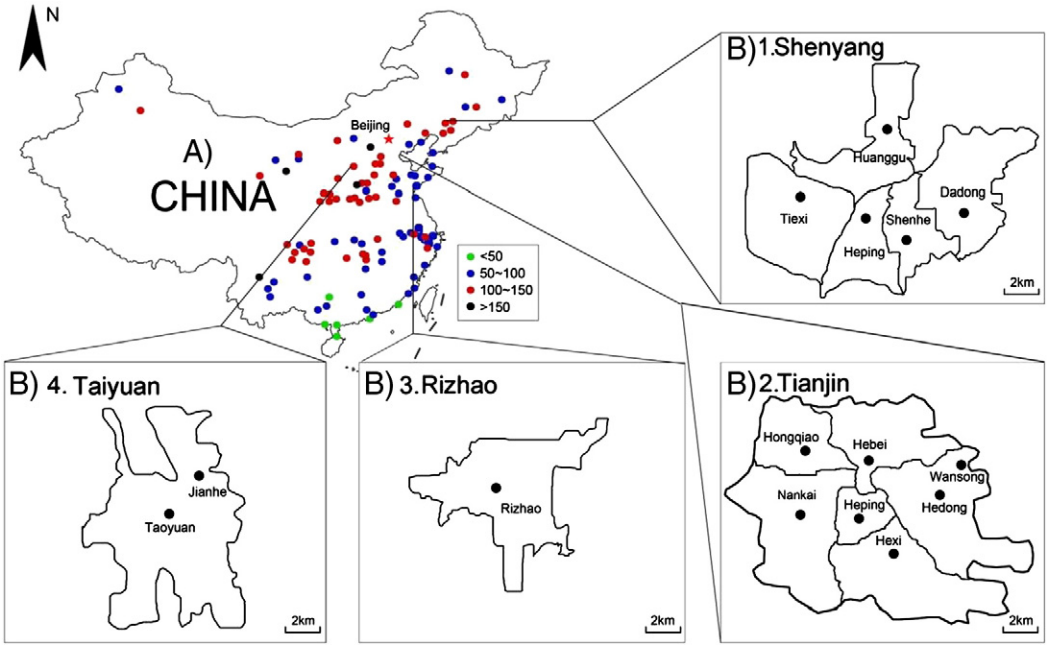

Fig. 1. (A) The distribution of PM_{10} concentrations in 108 Chinese cities in 2005 (μg/m^3) (Reference: (SEPA, 2006)). (B) Study areas and the locations of air pollution monitors in four cities in China.