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Assessing responses of cardiovascular mortality to particulate matter air pollution for pre-, during- and post-2008 Olympics periods

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ABSTRACT

Background: The link between particulate air pollution and cardiovascular (CVD) mortality has been investigated. However, there is little direct evidence that reduction measures which decrease particulate air pollution would lead to a reduction in CVD mortality.

Objectives: In Beijing, China, air quality improvement strategies were developed and actions were taken before and during the 2008 Olympic and Paralympic Games. Taking advantage of this opportunity, the aim of the study was to assess the effects of changes in particulate air pollution before (May 20–July 20, 2008), during (August 1–September 20, 2008) and after (October 1–December 1, 2008) the Olympics period.

Methods: Concentrations of air pollution, meteorology and CVD death counts were obtained from official networks and monitoring sites located on the Peking University campus. Air pollution effects with lags of 0–4 days as well as of the 5-day average on cause-specific CVD mortality were investigated for the complete study period (May 20–December 1, 2008) using Quasi-Poisson regression models. Different gender and age subgroups were taken into account. Additionally, effect modification by air mass origin was investigated. In a second step, air pollution effects were estimated for the three specific periods by including an interaction term in the models.

Results: We observed large concentration decreases in all measured air pollutants during the unique pollution intervention for the Beijing 2008 Olympics. For the whole period, adverse effects of particulate air pollution were observed on CVD mortality with a 1-day delay as well as for the 5-day average exposure, e.g. an 8.8% (95%CI: 2.7–15.2%) increase in CVD mortality with an interquartile range increase in ultrafine particles. The effects were more pronounced in females, the elderly and for cerebrovascular deaths, but not modified by air mass origin. The specific sub-period analysis results suggested that the risks of CVD mortality were lowest during the Olympic Games where strongest reduction measures have been applied.

Conclusions: The results indicated that the reduction of air pollution due to air quality control measures led to a decreased risk of CVD mortality in Beijing. Our findings provide new insight into efforts to reduce ambient air pollution.

1. Introduction

Consistent evidence worldwide shows that elevated concentrations of particulate matter (PM) are linked with increased cardiovascular mortality and morbidity (Brook et al., 2010; Pope and Dockery, 2006; Ruckerl et al., 2011).

In recent years, more and more epidemiological research focused on ultrafine particle (particles less than 0.1 μm in diameter; UFP). These have been suggested being more harmful to human

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health than larger particles, not only because of their high particle number concentration and larger active surface area, but also due to the high deposition efficiency in the pulmonary region (Delfino et al., 2005; Pekkanen and Kulmala, 2004). Moreover, it is assumed that UFP and associated toxics can translocate to the lung interstitium and may enter into the circulation. Thereby, they can increase oxidative stress responses as well as particle-induced pulmonary reflexes and inflammation which are all leading to adverse health effects (Brook et al., 2004; Nemmar et al., 2004; Oberdorster et al., 2002). The composition of UFP is dominated by carbon compounds, and it can be further divided into two sub-fractions-Nucleation mode particles and Aitken mode particles-which differ in dynamics and may have varying effects on health (Halonen et al., 2009; Hussein et al., 2004). Nucleation mode particles (less than 30 nm in diameter) are mainly formed via atmospheric nucleation and have a high short-term peak concentration so that they could make a substantial contribution to the exposure of inhalable particles (Kulmala et al., 2004). Aitken mode particles (with a diameter between 30 and 100 nm) are directly emitted from combustion processes, such as soot particles from traffic and may also result from condensation growth and coagulation of nucleation mode particles (Breitner et al., 2011; Halonen et al., 2009).

Due to limited availability of measurement data, estimates for the associations between particle number concentrations (PNC) in different size ranges and cardiovascular hospital admissions or mortality are still sparse (Branis et al., 2010; Breitner et al., 2011; Halonen et al., 2009; Meng et al., 2013; Peters et al., 2009; Stolzel et al., 2007). In China, relevant exposure data are even more rarely available to epidemiologists despite high particle concentrations (Wang et al., 2013; Wu et al., 2008).

According to a report by the HEI (Pope, 2009), accountability studies are a subset of epidemiologic studies that attempt to exploit policy-related, planned, or controlled interventions that result in changes (usually reduction) in exposure and/or exposure variability. A small number of studies have been conducted that fit within this research framework (Breitner et al., 2009). Examples are studies on the banning of coal sales in Dublin, Ireland (Clancy et al., 2002), the reduction of sulfur in fuels in Hong Kong, China (Hedley et al. 2002), and traffic restrictions during the 1996 Summer Olympic Games in Atlanta, Georgia, USA (Hedley et al., 2002; Peel et al., 2010) and the 2002 Asian Games in Busan, Korea (Lee et al., 2007).

The air quality in Beijing was a serious concern for the Chinese government with regard to the 2008 Summer Olympic Games and Paralympics. Therefore, air quality improvement strategies were developed, and actions were taken before and during the Olympics and Paralympics to ensure a substantial improvement of the ambient air quality in Beijing. In total, 12.2 billion US$ have been provided for the air pollution control measurements (Fang et al., 2009). One of the key measures for better air quality was traffic control. In addition, for example, manufactories with high air pollutant emissions were ordered to shut down during the Olympics, polluting industries were relocated, and more than 16,000 small coal-fired boilers were retrofitted from using coal to cleaner natural gas (Fang et al., 2009).

Such unprecedented measures to reduce the sources of air pollution offered a unique research opportunity to investigate whether the change in air quality within a short period would lead to changes in human health outcomes. Several studies have been conducted using this quasi-experimental design to explore the link between air pollution and human health (Gong et al., 2014; Huang et al., 2012; Lin et al., 2011; Rich et al., 2012; Zhang et al., 2013). However, most of these studies were limited to fine PM, and mainly focused on cardiorespiratory biomarkers; few of these were related to cardiovascular mortality.

Therefore, we designed this study to assess the effects of changes in particulate air pollution before, during and after the Olympic Games in Beijing, 2008, on cause-specific cardiovascular mortality.

2. Materials and methods

2.1. Study area

This study was conducted in the urban area of Beijing, China. Beijing is the capital city of China and is located about 150 km southeast of Bohai Sea in the North China plain. Mountains of 1000–1500 m to the north, northwest and west shield the city. In 2008, the urban area of Beijing comprised an area of about 1368 km^2 consisting of eight districts with approximately 12,299,000 registered residents (http://www.bjstats.gov.cn/tjnj/2009-tjnj/).

2.2. Study period

To ensure good air quality during the Summer Olympic Games (August 8–24, 2008) and Paralympics (September 9–17, 2008), the Ministry of Environmental Protection of the Peoples Republic of China and the Beijing Municipal Government jointly developed air pollution control measures, which were implemented to reduce emissions in both Beijing and surrounding areas during the Games (Fang et al., 2009). Fig. 1 shows some main air quality control measures as well as the executed time.

In this study, we investigated the association between air pollution and daily death counts for the period May 20–December 1, 2008. Additionally, we examined air pollution effects in three specific sub-periods: pre-Olympic (May 20–July 20, 62 days), during-Olympic (August 1–September 20, 51 days), and post-Olympic period (October 1–December 1, 62 days). We specified a 10-day transition interval between each period (Fig. 2).

2.3. Data collection

Cardiovascular mortality data were obtained from the Beijing Center for Disease Control (CDC) for the urban area of Beijing using the International Classification of Diseases and Related Health Problems 10th revision (ICD10). Daily death counts due to cardiovascular diseases (CVD) (ICD10: I00–I99) were further classified into: ischemic heart disease (IHD) (ICD10: I20–I25) and cerebrovascular disease (ICD10: I60–I69). For overall CVD mortality, we also investigated different gender (males and females) and age groups (0–74 years and $\geq$75 years).

Particle size distribution data were sampled on top of a six-floor building inside the campus of Peking University (PKU), which is located in the Haidian District (see Appendix Fig. A1). The PKU campus is a primarily residential and commercial area without industrial sources or agricultural activities. Local emission sources within a radius of 1 km could be vehicular traffic, fuel combustion for domestic cooking and heating, and construction. Average particle number size distributions at the PKU measurement site and another regional measurement site, located around 50 km to the south, were shown to be similar in summer (Yue et al., 2009), confirming that the PKU measurement site may be considered as an urban background station (Breitner et al., 2011). The setup of the measurement station has been described in detail elsewhere (Wehner et al., 2004, 2008). Briefly, a Twin Differential Mobility Particle Sizer was used to sample the size range from 3 nm to 800 nm (mobility diameter) (Birmili et al., 1999). Data were corrected for losses due to diffusion and sedimentation within the inlet line as described by Wehner et al. (2004). In this study, we