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Is short-term exposure to ambient fine particles associated with measles incidence in China? A multi-city study

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ABSTRACT

Background: China's rapid economic development has resulted in severe particulate matter (PM) air pollution and the control and prevention of infectious disease is an ongoing priority. This study examined the relationships between short-term exposure to ambient particles with aerodynamic diameter ≤2.5 μm ($PM_{2.5}$) and measles incidence in China.

Methods: Data on daily numbers of new measles cases and concentrations of ambient $PM_{2.5}$ were collected from 21 cities in China during Oct 2013 and Dec 2014. Poisson regression was used to examine city-specific associations of $PM_{2.5}$ and measles, with a constrained distributed lag model, after adjusting for seasonality, day of the week, and weather conditions. Then, the effects at the national scale were pooled with a random-effect meta-analysis.

Results: A 10 $\mu g/m^3$ increase in $PM_{2.5}$ at lag 1 day, lag 2 day and lag 3 day was significantly associated with increased measles incidence [relative risk (RR) and 95% confidence interval (CI) were 1.010 (1.003, 1.018), 1.010 (1.003, 1.016) and 1.006 (1.000, 1.012), respectively]. The cumulative relative risk of measles associated with $PM_{2.5}$ at lag 1–3 days was 1.029 (95% CI: 1.010, 1.048). Stratified analyses by meteorological factors showed that the $PM_{2.5}$ and measles associations were stronger on days with high temperature, low humidity, and high wind speed.

Conclusions: We provide new evidence that measles incidence is associated with exposure to ambient $PM_{2.5}$ in China. Effective policies to reduce air pollution may also reduce measles incidence.

1. Introduction

Numerous studies conducted since 1990's have provided cumulative evidence of the adverse health effects of particulate air pollution (Dockery, 2009). A recent global assessment estimated that 2.9 million deaths and 69.7 million disability-adjusted life-years per year were attributed to ambient particulate matter (PM) pollution (Forouzanfar et al., 2015). PM consists of both solid and liquid particles from various sources and the toxicity of PM is determined by particle size, surface area and chemical composition (Nel, 2005). Compared with coarse particles, fine particles with aerodynamic diameter ≤2.5 μm ($PM_{2.5}$) are more toxic, as they are inhaled more deeply into the lungs with longer residency times (Pope and Dockery, 2006).

Measles is a highly contagious disease which can lead to serious health consequences including death (Sotir et al., 2016), with a fatality rate of between 3% and 15% in high-income countries (Choe et al., 2015). In spite of the ongoing WHO vaccination program to eradicate measles worldwide since the 1990's, measles is still re-emerging in high-income countries (Holzmann et al., 2016) and measles outbreaks are still observed in upper middle-income countries, like China (Zhang et al., 2016a).

To date, most studies have focused on the effects of PM on cardiovascular and respiratory disease (Arnold, 2014). However, studies in recent years have also reported associations between PM and infectious diseases (e.g., influenza, hemorrhagic fever with renal syndrome and Hand, Foot, and Mouth Disease) (Feng et al., 2016; Han

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et al., 2013; Huang et al., 2016; Jang et al., 2015). Inhalation transports PM deep into the lung and virus attached to particles may invade the lower part of respiratory tract directly and thus enhance the induction of infections (Sedlmaier et al., 2009).

With the rapid economic growth and urbanization, China is experiencing very high concentrations of PM (Brauer et al., 2012). There are very few large-scale studies evaluating the health effects of PM in China due to the limited availability of data on health and air pollution. Particularly, no previous study has examined the relationship between short-term exposure to $PM_{2.5}$ and measles incidence in China. In this study, we examined the effects of $PM_{2.5}$ exposure on the daily incidence of new cases of measles in 21 cities in China with daily data on both ambient $PM_{2.5}$ and measles incidence.

2. Materials

2.1. Data collection

2.1.1. Measles data

Daily numbers of incident cases of measles for 21 cities between 28th Oct 2013 and 31th Dec 2014 were obtained from the China Information System for Disease Control and Prevention (CISDCP). China has established the large internet-based communicable disease reporting system covering the entire nation since 2004 which addressed the delays and under-reporting of communicable diseases (Wang et al., 2007). As measles is on the list of notified disease in China (Class B) (Wang et al., 2008), all hospitals and clinics within the National Notifiable Disease Reporting System are mandated to report each confirmed measles case which is diagnosed by subsequent routine laboratory examination (Ma et al., 2014). In this study, all measles cases were confirmed by both epidemiological linkage or clinical criteria and laboratory testing.

2.1.2. Ground $PM_{2.5}$ measurement and weather conditions

Daily ground-level $PM_{2.5}$ monitoring data during the same period as the measles data were obtained from China National Environmental Monitoring Center (CNEMC) administered by China Ministry of Environmental Protection. The monitoring data provided by CNEMC reflect the general background concentration of unban air pollution in Chinese cities. Details about ground measurements of $PM_{2.5}$ were reported elsewhere (Cao et al., 2011; Zhou et al., 2014). Meteorological data for the 21 cities during the study period were obtained from the China Meteorological Data Sharing Service System of China Meteorological Administration (http://data.cma.gov.cn). Daily data on temperature (^{0}C), relative humidity (%) and weed speed (km/h) were used for analysis.

2.2. Statistical analysis

The $PM_{2.5}$-measles association was examined by a two-stage analytic method with data on $PM_{2.5}$, count of incident measles cases and weather conditions in 21 cities in China using an approach previously described by Gasparrini et al. (Gasparrini et al., 2012, 2015; Guo et al., 2014). In the first stage, a time series model was used to estimate the city-specific $PM_{2.5}$-measles association, and in the second stage, these associations were pooled at the national level with a random-effect meta-analysis.

2.2.1. First stage of analysis

The City-specific $PM_{2.5}$-measles associations were examined with a time series Poisson regression model allowing for over-dispersion. A natural cubic spline with 7 degrees of freedom per year for time was used to control for the long-term trend and seasonality and a category variable was included in the model to control for the effect of day of the week (Peng et al., 2006). The delayed effects of meteorological factors (e.g., temperature, relative humidity and weed speed) were also controlled for with a seven-day moving average of each meteorological variable and a natural cubic spline with 4 degrees of freedom (Guo et al., 2013). To model the delayed effects of $PM_{2.5}$, a constrained distributed lag model (CDLM) was fitted for $PM_{2.5}$ using natural cubic splines with three degrees of freedom (Gasparrini, 2014). To evaluate the potential modifying effects of $PM_{2.5}$ on measles by meteorological factors, stratified analyses were performed by tertiles of 0–7 days' moving average of temperature, relative humidity and wind speed (as categorical variables) in each city during the study period (Atkinson et al., 1999; Chen et al., 2017).

2.2.2. Second stage of analysis

In the second stage, a meta-analysis was conducted to pool the city-specific $PM_{2.5}$-measles associations into a country-level effect estimate. The random-effects meta-analysis was fitted by maximum likelihood estimation to examine both within and between city variations regarding effect estimates (Gasparrini et al., 2012; Jackson et al., 2011). The pooled effect-estimates of $PM_{2.5}$ on measles were expressed as relative risks (RR) with a 10 μg/m^3 unit increase in $PM_{2.5}$ and corresponding 95% confidence intervals (CI) were also calculated.

Sensitivity analyses were also performed for city-specific models to test the robustness of results. The lag days were changed to 15 days for $PM_{2.5}$ to check whether the use of 7 lag days was sufficient to model its effects on measles. Precipitation was also included in the analysis. In addition, degrees of freedom for meteorological variables (3–6 df) and for time of the year (6–10 df) were modified. The stratified analyses with quartiles of meteorological variables were also performed and the results were compared with those using tertiles of meteorological variables. R software (version 3·2·2, R Development Core Team 2009) was used for all data analysis with "dnlm" and "mvmeta" packages.

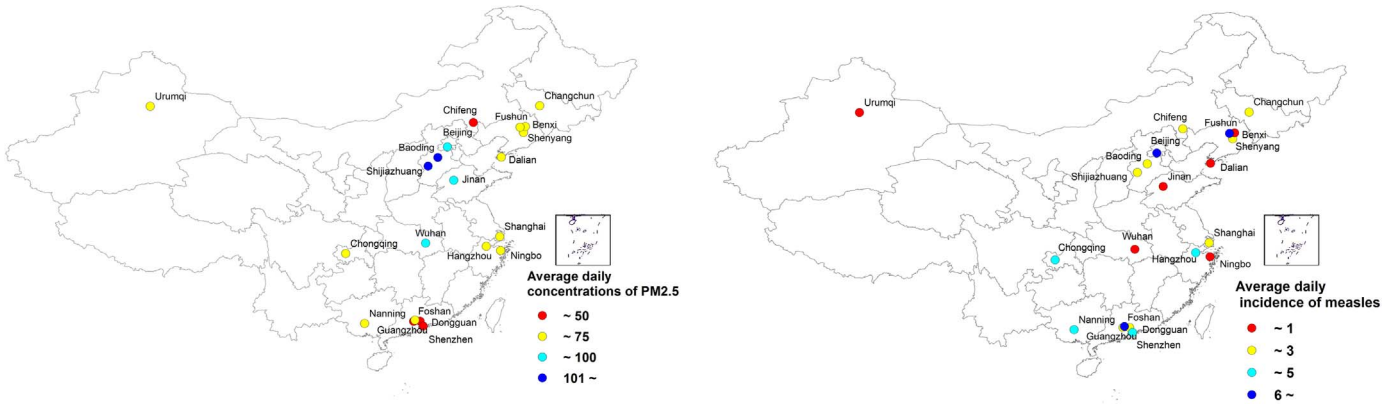

Fig. 1. Average daily concentrations of $PM_{2.5}$ (μg/m^3) and incidence of measles (average number per day) in 21 cities of China.