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<td>Author(s)</td>
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Effects of Coarse Particulate Matter on Emergency Hospital Admissions for Respiratory Diseases: A Time-Series Analysis in Hong Kong

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

Background: Many epidemiological studies have linked daily counts of hospital admissions to particulate matter (PM) with an aerodynamic diameter ≤ 10 μm (PM_{10}) and ≤ 2.5 μm (PM_{2.5}), but relatively few have investigated the relationship of hospital admissions with coarse PM (PM_{c} 2.5–10 μm aerodynamic diameter).

Objectives: We conducted this study to estimate the health effects of PM_{c} on emergency hospital admissions for respiratory diseases in Hong Kong after controlling for PM_{2.5} and gaseous pollutants.

Methods: We conducted a time-series analysis of associations between daily emergency hospital admissions for respiratory diseases in Hong Kong from January 2000 to December 2005 and daily PM_{2.5} and PM_{c} concentrations. We estimated PM_{c} concentrations by subtracting PM_{2.5} from PM_{10} measurements. We used generalized additive models to examine the relationship between PM_{c} (single- and multiday lagged exposures) and hospital admissions adjusted for time trends, weather conditions, influenza outbreaks, PM_{2.5}, and gaseous pollutants (nitrogen dioxide, sulfur dioxide, and ozone).

Results: A 10.9-μg/m^{3} (interquartile range) increase in the 4-day moving average concentration of PM_{c} was associated with a 1.94% (95% confidence interval: 1.24%, 2.64%) increase in emergency hospital admissions for respiratory diseases that was attenuated but still significant after controlling for PM_{2.5}. Adjusting for gaseous pollutants and altering models assumptions had little influence on PM_{c} effect estimates.

Conclusion: PM_{c} was associated with emergency hospital admissions for respiratory diseases in Hong Kong independent of PM_{2.5} and gaseous pollutants. Further research is needed to evaluate health effects of different components of PM_{c}.

Keywords: coarse particulate matter, emergency hospital admissions, fine particulate matter, generalized additive model, respiratory diseases, time-series study. Environ Health Perspect 120:572–576 (2012). http://dx.doi.org/10.1289/ehp.1104002 [Online 20 January 2012]

Data on particulate pollutants and meteorology variables. We obtained air pollution data for January 2000 through December 2005 from the Environmental Protection Department. There are a total of 11 general monitoring stations in Hong Kong. All of them monitored PM_{10} and gaseous pollutants [nitrogen dioxide (NO_{2}), sulfur dioxide (SO_{2}), and ozone (O_{3})] during the study period, but only three (Tuen Wan, Tap Mun, and Tung Chung) collected simultaneous PM_{2.5} data. The Tap Mun and Tung Chung stations are located in remote areas of Hong Kong, whereas the Tuen Wan station is located close to the geographic center of Hong Kong (Figure 1) and thus is likely to be more representative of Hong Kong’s air quality in general. In addition, the Tuen Wan station is not in direct proximity to traffic, industrial sources, buildings, or residential sources of emissions from the burning of coal, waste, or oil. Therefore, instead of estimating average values for the three stations with simultaneous PM_{10} and PM_{2.5} data, we used data from the Tuen Wan station only. We calculated 24-hr mean concentrations from nonmissing data if at least 18 of 24 hourly concentrations of PM_{10} or PM_{2.5} were available, and we did not impute data for the 195 days with missing PM_{c}, which accounted for only 8.9% of the study period. We estimated PM_{c} concentrations by subtracting daily mean PM_{2.5} from PM_{10}. In contrast with studies that examined PM_{c} using data collected every 3 or 6 days (Lin et al. 2005; Peng et al. 2008), we analyzed daily PM_{c} data available during the study period. We also calculated daily 24-hr mean concentrations of NO_{2}, SO_{2}, and 8-hr mean (1000 hours to 1800 hours) concentrations of O_{3} using data from the Tuen Wan station and collected daily mean temperature and relative humidity data for the same period from the Hong Kong Observatory.

Materials and Methods

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We thank the Hong Kong Environmental Protection Department for providing air pollution data, the Hong Kong Observatory for providing temperature and humidity data, and the Hospital Authority for providing hospital admissions data. We also thank W. Goggins for his advice on statistical modeling.

The authors declare they have no actual or potential competing financial interests.

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Data on hospital admissions. We collected citywide emergency hospital admissions (admissions through the accident and emergency services) for respiratory diseases in Hong Kong from January 2000 through December 2005. The hospitals included for compilation of hospital admissions were publicly funded hospitals that provide 24-hr accident and emergency services and 90% of hospital beds for Hong Kong residents (Wong et al. 1999). Patient data captured from the computerized medical record system included age, date of admission, source of admission, hospital, residential area, and principal diagnosis on discharge (International Statistical Classification of Diseases, 9th Revision (ICD-9); World Health Organization 1975)). We chose hospital admissions through accident and emergency services for diseases of the respiratory system (ICD-9 codes 460–519, excluding influenza (487.0–487.8) and for COPD (ICD-9 codes 491, 492, and 496) and asthma (ICD-9 code 493) specifically. We excluded influenza from respiratory diseases because a previous study demonstrated that influenza outbreaks may confound associations between PM and hospital admissions for respiratory diseases (Ren et al. 2006). We also compiled data on emergency hospital admissions for respiratory diseases among patients who are residents of the Tsuen Wan region (TW residents; residential addresses in the area around the Tsuen Wan air monitoring station, including Tsuen Wan, Kwai Tsing, and Sham Shui Po districts; Figure 1), to evaluate the potential influence of exposure misclassification.

Statistical methods. We used generalized additive modeling (GAM) with a log link and allowed Poisson autoregression and over-dispersion to model the relationship between daily PMc concentrations and health outcomes (Hastie and Tibshirani 1990). All models were adjusted for the day of the week (DOW) and public holidays using categorical indicator variables (Schwartz et al. 1996), and for influenza outbreaks using a dichotomous variable to indicate weeks during which the number of influenza hospital admissions exceeded the 75th percentile for the year (Wong CM et al. 2002). In addition, we used penalized smoothing splines (Host et al. 2008; Kan et al. 2007) to adjust for seasonal patterns and long-term trends in daily morbidity, temperature, and relative humidity with degrees of freedom (df) selected a priori based on previous studies (Bell et al. 2008; Peng et al. 2008). Specifically, we used 7 df per year for time trend, 6 df for mean temperature on the current day (Temp0) and the moving average for the previous 3 days (Temp1–3), and 3 df for humidity (Humidity) on the current day.

The resulting core model to estimate \( E\left( Y_t \right) \), the expected daily emergency respiratory hospital admission count on day \( t \), was specified as

\[
\log\left[E\left( Y_t \right) \right] = \alpha + s(t, df = 7/\text{year}) + s(\text{Temp}0, df = 6) + s(\text{Temp}1–3, df = 6) + s(\text{Humidity}, df = 3) + \beta_1 \times \text{DOW} + \beta_2 \times \text{Holiday} + \beta_3 \times \text{Influenza},
\]

where \( s(\cdot) \) indicates a smoother based on penalized splines, and \( \beta \) are regression coefficients.

To minimize autocorrelation, which would bias the standard errors, we specified that the absolute values of the partial autocorrelation function for the model residuals had to be < 0.1 for the first 2 lag days (Wong et al. 2008b). When these criteria were not met, we added autoregressive terms for the outcome variable to Equation 1, resulting in the addition of three autoregressive terms (lag1, lag2, lag3) to model emergency hospital admissions for total respiratory diseases, two autoregressive terms (lag1, and lag2) to model COPD, and one autoregressive term (lag3) for asthma. We also estimated the linear effect of PMc according to different lag structures, including single-day lags (current day (lag0) up to 5 days before (lag5)) and multiday lags (moving averages for the current day and the previous 1, 2, or 3 days: lag01, lag02, and lag03, respectively). However, we focused on 4-day average PMc exposure (lag03) for two-pollutant models and sensitivity analyses (Chen et al. 2004). In addition, we estimated the effect of PMc on emergency respiratory hospitalizations after adjusting for exposures to gaseous pollutants (NO2, SO2, and O3). To justify the assumption of linearity between the logarithm of emergency hospital admissions and particle concentrations, we graphically examined concentration–response relationships derived using a smoothing function (Kan et al. 2007; Wong CM et al. 2002).

Sensitivity analysis. In addition to analyzing the entire range of particulate concentrations, we estimated effects after excluding days with extremely high or low PMc or PM2.5 concentrations (i.e., excluding days with the highest 1% and lowest 1% of values). We also examined the impact of degrees of freedom selection for time trend and weather conditions on PMc effect estimates. To address possible exposure misclassification resulting from the use of pollution data from a single monitoring station, we did a sensitivity analysis restricted to emergency respiratory hospital admissions among TW residents.

We conducted all analyses using the MGCV package in R (version 2.10.0; R Development Core Team, Vienna, Austria). We report results as the percent increase [ERR, with 95% confidence intervals (CI)] in daily emergency respiratory hospital admissions for an interquartile range (IQR) increase in PM concentrations.

Results. From 1 January 2000 to 31 December 2005, we recorded a total of 710,247 hospital admissions for respiratory diseases in the study population. Of these, we included 518,864 hospital admissions through accident and emergency

![Figure 1. Location of the Tsuen Wan air monitoring station, Tsuen Wan region (dark-gray area), and the other general air monitoring stations (black circles) in Hong Kong.](Image 220x74 to 560x339)
services (emergency hospital admissions) in our analyses. On average, there were 237 emergency hospital admissions per day for total respiratory diseases, 81 for COPD, and 20 for asthma (Table 1). The average number of daily emergency hospital admissions among TW residents was about 50 per day.

Daily mean concentrations of PM$_{2.5}$ and PM$_{10}$ were 39.4 and 16.6 μg/m$^3$, with IQRs of 26.3 and 10.9 μg/m$^3$, respectively (Table 1). PM$_{10}$ accounted for a substantial part of the mass concentration of PM$_{10}$ in Hong Kong: the ratio of PM$_{2.5}$ to PM$_{10}$ ranged from 40% to 98%, with an average of 70%. Therefore, PM$_{10}$ accounted for about 30% of PM$_{10}$ mass concentration. Daily mean concentrations of NO$_2$, SO$_2$, and O$_3$ were 64.4, 22.9, and 31.1 μg/m$^3$, respectively (Table 1). PM$_{10}$ was strongly correlated with PM$_{2.5}$ (correlation coefficient, $r = 0.97$) and with PM$_c$ ($r = 0.84$), and PM$_{2.5}$ and PM$_c$ were moderately correlated ($r = 0.68$; Table 2). Correlation coefficients for PM$_c$ and gaseous pollutants were low to moderate ($r = 0.56$ for NO$_2$, $r = 0.27$ for SO$_2$, $r = 0.37$ for O$_3$).

**Regression results.** PM$_c$ was significantly associated ($p < 0.05$) with total respiratory and COPD emergency hospital admissions at most of the lags examined in single-pollutant models, whereas associations with asthma hospitalization were positive but only statistically significant at lags 0, 1, 2, 3, and 4 (Figure 2). An IQR increase in the 4-day moving average concentration of PM$_c$ (lag0) was associated with 1.94% (95% CI: 1.24%, 2.64%), 3.37% (2.26%, 4.49%), and 2.32% (0.14%, 4.55%) increases in emergency hospital admissions for total respiratory diseases, COPD, and asthma, respectively (Table 3). After adjusting for PM$_{2.5}$ in two-pollutant models, estimated effects of PM$_c$ on respiratory and COPD hospital admissions were attenuated but remained statistically significant, with ERs of 1.05% (95% CI: 0.19%, 1.91%) and 1.78% (0.41%, 3.16%), respectively. However, the effect estimate for PM$_c$ on asthma hospitalizations was close to the null after adjustment for PM$_{2.5}$ (Table 3). Adjustment for gaseous pollutants had little influence on effect estimates for associations between PM$_c$ and total respiratory hospitalizations (Table 4).

The concentration–response curve for PM$_c$ and emergency hospital admissions for total respiratory diseases tended to plateau at higher concentrations of PM$_c$, but estimates were imprecise because of limited data in this range (Figure 3A). After we excluded the highest 1% and the lowest 1% extremes of PM$_c$ concentrations, the curve appeared essentially linear (Figure 3B). The estimated effect (slope) of PM$_c$ modeled as a linear variable increased slightly after excluding days with extreme concentrations, both before and after adjustment for PM$_{2.5}$ (Table 4).

Varying the degrees of freedom for time trend (within the range of 6–12 per year) and weather conditions (mean temperature and humidity, within the range of 3–12) did not affect the regression results substantially (Figure 4), suggesting that effect estimates for PM$_c$ were relatively robust to changes in degrees of freedom for model covariates. ERR estimates based on data restricted to emergency respiratory hospitalizations among TW residents were less precise but slightly higher than corresponding estimates based on all observations.

**Discussion**

This study is one of the few to investigate the association between PM$_c$ and respiratory hospitalizations. We found significant positive associations between PM$_c$ concentrations and emergency hospital admissions for respiratory diseases in Hong Kong. To our knowledge, this study is the largest single-city study to date of the effects of PM$_c$ on emergency hospital admissions for respiratory diseases, including more than half a million admissions over 6 years. In contrast with studies based on PM data collected every third or sixth day (Lin et al. 2005; Peng et al. 2008), we evaluated daily data and were able to estimate effects of multiday average concentrations of PM$_c$, which were larger in magnitude than estimated effects of single-day lags in most

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Table 1. Summary statistics of daily emergency hospital admissions, air pollution concentrations, and weather conditions in Hong Kong, 2000–2005.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Minimum</th>
<th>25th</th>
<th>50th</th>
<th>75th</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily emergency hospital admissions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total respiratory diseases</td>
<td>236.7 ± 55.4</td>
<td>89</td>
<td>198</td>
<td>230</td>
<td>269</td>
<td>518</td>
</tr>
<tr>
<td>COPD</td>
<td>81.1 ± 20.3</td>
<td>22</td>
<td>68</td>
<td>80</td>
<td>95</td>
<td>165</td>
</tr>
<tr>
<td>Asthma</td>
<td>19.6 ± 8.0</td>
<td>1</td>
<td>14</td>
<td>19</td>
<td>25</td>
<td>61</td>
</tr>
<tr>
<td>Respiratory diseases in TW residents</td>
<td>50.0 ± 12.4</td>
<td>18</td>
<td>41</td>
<td>49</td>
<td>57</td>
<td>104</td>
</tr>
<tr>
<td><strong>Pollution concentration (μg/m$^3$)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>56.1 ± 27.8</td>
<td>13.5</td>
<td>34.9</td>
<td>49.2</td>
<td>72.5</td>
<td>231.5</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>39.4 ± 20.7</td>
<td>8.9</td>
<td>23.8</td>
<td>34.8</td>
<td>50.1</td>
<td>179.8</td>
</tr>
<tr>
<td>PM$_c$</td>
<td>16.6 ± 9.2</td>
<td>0.8</td>
<td>10.0</td>
<td>14.5</td>
<td>20.9</td>
<td>82.9</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>64.4 ± 22.4</td>
<td>13.0</td>
<td>48.4</td>
<td>61.6</td>
<td>77.4</td>
<td>193.9</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>22.9 ± 17.1</td>
<td>1.0</td>
<td>11.3</td>
<td>18.3</td>
<td>28.7</td>
<td>143.3</td>
</tr>
<tr>
<td>O$_3$</td>
<td>31.1 ± 24.3</td>
<td>1.0</td>
<td>13.2</td>
<td>24.2</td>
<td>42.8</td>
<td>171.7</td>
</tr>
<tr>
<td><strong>Meteorology measures</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Temperature (°C)</td>
<td>23.5 ± 5.0</td>
<td>8.2</td>
<td>19.6</td>
<td>24.9</td>
<td>27.8</td>
<td>31.8</td>
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<tr>
<td>Relative humidity (%)</td>
<td>78.2 ± 9.7</td>
<td>32</td>
<td>73</td>
<td>79</td>
<td>85</td>
<td>97</td>
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</table>

Minimum is the lowest value, and maximum is the highest value in the full range.

Table 2. Pearson correlation coefficients between PM concentrations, gaseous pollutants, and weather conditions.

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>PM$_{10}$</th>
<th>PM$_{2.5}$</th>
<th>PM$_c$</th>
<th>NO$_2$</th>
<th>SO$_2$</th>
<th>O$_3$</th>
<th>Temperature</th>
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<tr>
<td>PM$_{10}$</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>0.986</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM$_c$</td>
<td>0.936</td>
<td>0.575</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO$_2$</td>
<td>0.771</td>
<td>0.796</td>
<td>0.560</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO$_2$</td>
<td>0.432</td>
<td>0.461</td>
<td>0.267</td>
<td>0.493</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O$_3$</td>
<td>0.475</td>
<td>0.472</td>
<td>0.370</td>
<td>0.303</td>
<td>0.022</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>–0.304</td>
<td>–0.285</td>
<td>–0.278</td>
<td>–0.298</td>
<td>0.163</td>
<td>0.054</td>
<td>1.000</td>
</tr>
</tbody>
</table>

*All correlation coefficients except that between O$_3$ and SO$_2$ are statistically significant ($p < 0.05$).
cases. We estimated statistically significant positive associations between PMc and emergency hospital admissions for total respiratory diseases and COPD for almost all lags examined. The estimated effect of PMc on asthma appeared to be strongest several days after exposure, consistent with a previous study (Lin et al. 2002).

Positive associations between PMc and total emergency respiratory hospitalizations, especially COPD, remained after adjusting for PM2.5, but the estimated effect of PMc on emergency asthma hospitalizations was close to the null after adjusting for PM2.5. A few studies estimated effects of PMc on respiratory admissions after adjusting for PM2.5 (Burnett et al. 1999; Chen et al. 2004; Ito 2003; Peng et al. 2008), but only one (Burnett et al. 1999) reported statistically significant associations independent of PM2.5. However, unlike the daily measurements used in our study, daily levels of PMc and PM2.5 in that study were estimated from 6-day sampling and not directly measured. Two studies have reported positive associations between PMc and asthma hospitalization in children, but estimates were not adjusted for PM2.5 (Lin et al. 2002; Tecer et al. 2008). Estimated effects of PMc changed very little after we adjusted for possible confounding effects of gaseous pollutants (NO2, SO2, O3), and others have also reported positive associations between PMc and respiratory hospitalizations after adjusting for gaseous pollutants (Chen et al. 2004, 2005; Lin et al. 2002, 2005). The correlation coefficients between PMc and gases in these Canadian studies were low to moderate, consistent with our study (correlation coefficients ranging from 0.27 for PMc and SO2 to 0.56 for PMc and NO3).

Englert (2004) suggested that the relative sizes of effects attributed to fractions of PM10 depend on their relative mass percentages. Although PMc, represented only about 30% of the PM10 mass concentration in our study, we estimated statistically significant ERRs for emergency respiratory hospital admissions in association with PMc, which supports a specific effect of this PM fraction.

The concentration–response relationship between PMc and emergency hospital admissions for total respiratory diseases was almost linear after excluding the highest 1% extreme concentrations of PMc, and the slope of the estimated association based on a linear model increased slightly. Our results were not substantially modified when we varied the degrees of freedom for smooths of time and weather conditions. Analyses restricted to emergency hospitalizations among residents living near the monitoring station also were consistent with the overall results, which supports the use of PM data from a single central monitoring station in our main analyses.

Effects may vary for PMc from different sources and with different chemical compositions, and it has been proposed that differences...
in associations estimated for Hong Kong and U.S. populations (Peng et al. 2008) might be explained by differences in PM composition. Further studies are needed to examine the health effects of the specific components in PMc.

Smaller particles offer a proportionally larger surface area resulting in potentially higher concentrations of adsorbed or condensed toxic air pollutants per unit mass. Hence, PM$_{2.5}$ is frequently assumed to be a more relevant exposure indicator than larger particles. However, the pathological mechanisms of particles on human health are not fully understood. Particle size may be associated with chemical, biological, and physical properties that contribute to specific pathological mechanisms. PM$_{c}$ originates mainly from the soil and abrasive mechanical processes and thus may carry biological materials such as bacteria, molds, or pollens that can produce adverse health effects in the respiratory system (Almeida et al. 2006). Our results lend support to possible adverse health effects of PM$_{c}$ exposure that are independent of PM$_{2.5}$ and gaseous pollutants. Further study of seasonal differences in PM$_{c}$ composition and season-specific PM$_{c}$ effects may help clarify pathological mechanisms.

Some limitations of the present study should be noted. We estimated PM$_{c}$ concentrations by subtracting PM$_{2.5}$ from PM$_{1.0}$ measurements. A disadvantage of this method is that PM$_{c}$ exposure estimates are subjected to two sources of random error in measurement (standard error) rather than one, which may reduce the statistical power of detecting an association. Because we still observed significant associations between PM$_{c}$ and emergency respiratory hospital admissions in Hong Kong, these were likely true associations. As in other time-series studies, we used available outdoor monitoring data to represent the population exposure to ambient particles. Indoor air pollution and personal exposure data were not available. A simulation using data from a recent multipollutant (PM$_{2.5}$, O$_3$, and NO$_2$) exposure assessment study conducted in Baltimore, Maryland (USA), suggested that for PM$_{2.5}$ and gaseous pollutants. Further study of seasonal differences in PM$_{c}$ composition and season-specific PM$_{c}$ effects may help clarify pathological mechanisms.

In conclusion, we found evidence indicating that PM$_{c}$ may play an important role in emergency hospitalizations for respiratory diseases independent of PM$_{2.5}$ and other gaseous pollutants. Our findings in Hong Kong add to the growing body of literature concerning adverse health effects of PM$_{c}$. However, further studies are needed to elucidate toxicological differences related to effects of PM$_{c}$ with different compositions under different situations of time and place and to identify PM$_{c}$ component(s) posing the greatest health risk.

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