Coarse Particulate Matter Air Pollution and Hospital Admissions for Cardiovascular and Respiratory Diseases Among Medicare Patients

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Coarse Particulate Matter Air Pollution and Hospital Admissions for Cardiovascular and Respiratory Diseases Among Medicare Patients

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Context Health risks of fine particulate matter of 2.5 μm or less in aerodynamic diameter ($PM_{2.5}$) have been studied extensively over the last decade. Evidence concerning the health risks of the coarse fraction of greater than 2.5 μm and 10 μm or less in aerodynamic diameter ($PM_{10-2.5}$) is limited.

Objective To estimate risk of hospital admissions for cardiovascular and respiratory diseases associated with $PM_{10-2.5}$ exposure, controlling for $PM_{2.5}$.

Design, Setting, and Participants Using a database assembled for 108 US counties with daily cardiovascular and respiratory disease admission rates, temperature and dew-point temperature, and $PM_{10-2.5}$ and $PM_{2.5}$ concentrations were calculated with monitoring data as an exposure surrogate from January 1, 1999, through December 31, 2005. Admission rates were constructed from the Medicare National Claims History Files, for a study population of approximately 12 million Medicare enrollees living on average 9 miles (14.4 km) from collocated pairs of PM_{10} and $PM_{2.5}$ monitors.

Main Outcome Measures Daily counts of county-wide emergency hospital admissions for primary diagnoses of cardiovascular or respiratory disease.

Results There were 3.7 million cardiovascular disease and 1.4 million respiratory disease admissions. A 10-μg/m^3 increase in $PM_{10-2.5}$ was associated with a 0.36% (95% posterior interval [PI], 0.05% to 0.68%) increase in cardiovascular disease admissions on the same day. However, when adjusted for $PM_{2.5}$, the association was no longer statistically significant (0.25%; 95% PI, –0.11% to 0.60%). A 10-μg/m^3 increase in $PM_{10-2.5}$ was associated with a nonstatistically significant unadjusted 0.33% (95% PI, –0.21% to 0.86%) increase in respiratory disease admissions and with a 0.26% (95% PI, –0.32% to 0.84%) increase in respiratory disease admissions when adjusted for $PM_{2.5}$. The unadjusted associations of $PM_{2.5}$ with cardiovascular and respiratory disease admissions were 0.71% (95% PI, 0.45%-0.96%) for same-day exposure and 0.44% (95% PI, 0.06% to 0.82%) for exposure 2 days before hospital admission.

Conclusion After adjustment for $PM_{2.5}$, there were no statistically significant associations between coarse particulates and hospital admissions for cardiovascular and respiratory diseases.

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Regulatory control of airborne particulate matter is hindered by an uncertain understanding of the toxicity of the particulate matter mixture. The National Research Council's Committee on Research Priorities for Airborne Particulate Matter identified the limited information on the health effects of particulate matter characteristics, including size, as a key area for research.[1] Numerous epidemiological studies have been published on risks associated with particulate matter that is 10 μm or less in diameter (PM_{10}).[2] More recent work has focused on particulate matter that is 2.5 μm or less in diameter ($PM_{2.5}$), for which strong evidence of an association with mortality and morbidity has been found.[3,4] Research on the health effects of coarse thoracic particles in the size range of greater than 2.5 μm and 10 μm or less in diameter ($PM_{10-2.5}$) is limited and findings have been mixed.[5] The chemical composition of particulate matter differs by size with more crustal materials in $PM_{10-2.5}$ and more combustion-related constituents in $PM_{2.5}$.[6-8] The health effects associated with ambient exposure to $PM_{10-2.5}$ could differ from those of $PM_{2.5}$ given differences in the sites of deposition in the respiratory tract and the sources and chemical composition for these 2 different-sized fractions.

Coarse particles, which are produced primarily by processes such as mechanical grinding, windblown dust, and agricultural activities, deposit pref-

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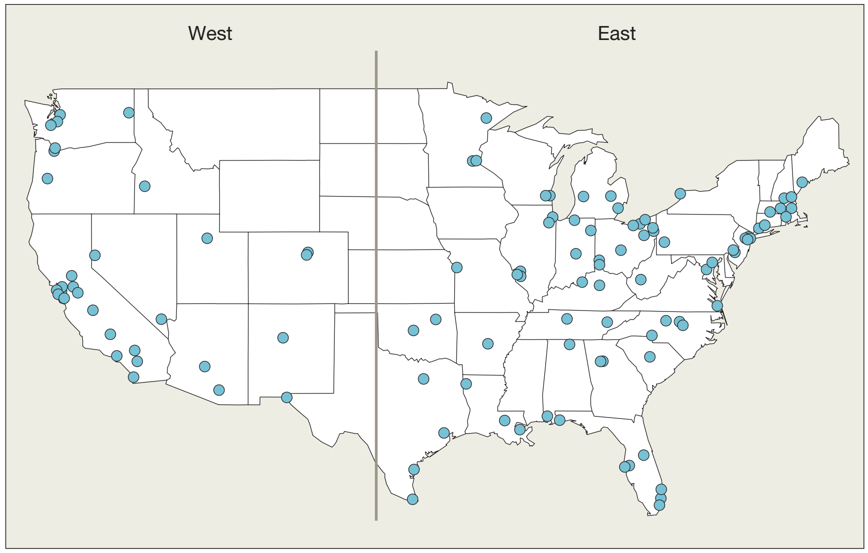
erentially in the upper and larger airways. Particles in the $PM_{2.5}$ size range, which are more likely to result from combustion processes, can reach the smaller airways and alveoli.[9] Various pathogenetic processes have been proposed as relevant for particles, regardless of size.[9,10]

Evidence on risks associated with $PM_{10-2.5}$ is relevant to current regulations for particulate matter. In 1997, the US Environmental Protection Agency (EPA) introduced a National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$, and maintained the PM_{10} standard to cover $PM_{10-2.5}$. In 2005, the EPA proposed a revised NAAQS for particulate matter that included daily and annual standards for $PM_{2.5}$ and a further proposal for replacing the existing daily PM_{10} standard with a daily $PM_{10-2.5}$ standard in urban areas only.[11] In proposing the standard, the EPA cited several epidemiological studies and background information on dosimetry in the respiratory tract by size.[9,12] However, its final NAAQS for particulate matter in 2006 did not include this $PM_{10-2.5}$ standard. The EPA recognized that the evidence base on the health effects of $PM_{10-2.5}$ was still inadequate and that further research on the health effects of coarse thoracic particles was needed.[9]

The implementation of national monitoring for $PM_{2.5}$ and the continuation of some PM_{10} monitoring provided an opportunity to calculate $PM_{10-2.5}$ concentrations for 108 US counties from January 1, 1999, through December 31, 2005, and to conduct a multisite time-series study using this particulate matter indicator as an exposure surrogate. These 108 counties are a subset of the 204 counties included in our previous study.[3] Each county had at least 1 pair of collocated monitors (physically located in the same place) for PM_{10} and $PM_{2.5}$. The $PM_{10-2.5}$ concentrations were calculated as the difference between PM_{10} and $PM_{2.5}$ concentrations, which is done routinely by the EPA.[13] The associations between daily average exposure to $PM_{10-2.5}$ and risk for hospitalization by county were estimated and then combined with the county-specific estimates to generate regional and national effects, following previously developed methods.[3,14-16]

Figure 1. US Counties With a General Population Larger Than 200 000 and With at Least 210 Daily Measurements of Collocated PM_{10} and $PM_{2.5}$ Data Between 1999 and 2005



Measurements are for 108 counties. The vertical line divides the east and west regions. PM_{10} indicates particulate matter is 10 μm or less in aerodynamic diameter; $PM_{2.5}$, particulate matter is 2.5 μm or less in aerodynamic diameter.

METHODS

This analysis was based on daily counts of emergency hospital admissions for 1999-2005 derived from billing claims of Medicare enrollees from the National Claims History Files. Because the Medicare data analyzed for this study did not include individual identifiers, consent was not specifically obtained. This study was reviewed and exempted by the institutional review board at the Johns Hopkins Bloomberg School of Public Health.

Each billing claim includes age, sex, and race, the date of service, disease classification in accordance with the *International Classification of Diseases, Ninth Revision* (*ICD-9*), and county of residence. In 2006, there were 36.3 million Medicare enrollees aged 65 years or older, representing more than 90% of the US population older than 65 years.[17] Two broad classes of outcomes were considered based on the *ICD-9* codes. Cardiovascular admissions included heart failure (428), heart rhythm disturbances (426-427), cerebrovascular events (430-438), ischemic heart disease (410-414, 429), and peripheral vascular disease (440-448). Respiratory admissions included chronic obstructive pulmonary disease (490-492) and respiratory tract infections (464-466, 480-487). For each outcome, only the primary diagnosis for the hospital admission was considered as the basis for inclusion in the data set. Daily time series of hospitalization rates were constructed by cause for each county by summing the number of emergency hospital admissions for each day in a county for a given outcome.

Our study population consists of approximately 12 million Medicare enrollees living on average 9 miles (14.4 km) from a collocated pair of $PM_{2.5}$ and PM_{10} monitors with data in the EPA's Air Quality System. The analysis was restricted to 108 counties with a general population larger than 200 000 in 2000 and with at least 210 daily measurements of collocated PM_{10} and $PM_{2.5}$ data between 1999 and 2005. A map of the 108 counties is shown in FIGURE 1. The schedule for measuring $PM_{2.5}$ was generally 1 every 3 days, while the schedule for measuring PM_{10} was more commonly 1 every 6 days. A 10% trimmed mean was used when averaging values across monitors within a county, after adjusting for yearly averages within each monitor.[18,19] County-specific information is available at http://www.biostat.jhsph.edu/rr/coarse/countyinfo.html. Temperature and dew-point temperature data were obtained from the National Climatic Data Center on the Earth-Info CD database.

Because $PM_{10\text{-}2.5}$ is not measured directly, its concentration was estimated using the measurements of PM_{10} and $PM_{2.5}$ at each location. An indicator of $PM_{10\text{-}2.5}$ was constructed by subtracting the daily measurements of PM_{10} and $PM_{2.5}$ at collocated monitors. These differences were averaged across a county using a trimmed mean if the county had multiple collocated monitoring pairs.

Two-stage Bayesian hierarchical models were applied to estimate national and regional average associations between day-to-day variation in $PM_{10\text{-}2.5}$ (at lags 0, 1, and 2 days) and day-to-day variation in county-level hospital admission rates, adjusting for $PM_{2.5}$, weather, and seasonal and long-term trends in both $PM_{10\text{-}2.5}$ and admission rates.

A power of 80% was estimated to detect a national average relative risk (RR) as small as 0.45% per 10 $\mu g/m^3$ for cardiovascular disease and 0.81% per 10 $\mu g/m^3$ for respiratory disease.

In the first stage, overdispersed Poisson models were fit to the county-specific data to obtain estimates of the RR of hospital admissions associated with $PM_{10\text{-}2.5}$. Two parallel time series of admissions were created for those aged 65 to 74 years and for those aged 75 years or older. These county-specific models included (1) the logarithm of the number of people at risk on a given day as an offset; (2) an indicator of the day of the week; (3) age-specific intercept; (4) smooth functions of the current day's temperature and the mean of the previous 3 days' temperatures (each using 6 degrees of freedom); (5) smooth functions of the current day's dew-point temperature and the mean of the previous 3 days' dew-point temperatures (3 degrees of freedom); (6) a smooth function of calendar time (8 degrees of freedom per calendar year); (7) an indicator for age of 75 years or older; (8) a smooth function of time and age indicator interaction (1 degree of freedom per year); and (9) the daily concentration of $PM_{10\text{-}2.5}$ at a given lag. Each of the smooth functions in the model was represented using natural cubic splines.

For the smooth functions of calendar time, 8 degrees of freedom per year was chosen for the smoother so that little information at time scales longer than 2 months would be retained in estimating the risks. For temperature, 6 degrees of freedom was chosen to give the model sufficient flexibility to account for potential nonlinearity in the relationship between temperature and health outcomes.[20]

At the second stage, a national average estimate of the short-term association between $PM_{10\text{-}2.5}$ and hospital admissions was obtained by using Bayesian hierarchical models.[21-24] These models combine RRs across counties accounting for within-county statistical error and for between-county variability of the true RRs (also called heterogeneity). The posterior probability that the national average effect is positive, as a measure of the strength of the evidence of an association, also was calculated. Significance *is* assessed by the posterior probability that the RR is greater than 0 (values greater than 0.95 are considered significant). To produce regional estimates for the eastern and western United States, the county-specific RR estimates across 77 counties in the eastern region and 31 counties in the western region were combined. Counties were defined to be in the eastern region if they had a longitude greater than −100 (Figure 1), following previous regional comparisons of the health effects of $PM_{2.5}$.[3]

To gauge the potential public health impact of the risk estimates, the annual reduction in admissions (H) attributable to a 10-$\mu g/m^3$ reduction in the daily $PM_{10\text{-}2.5}$ level for the 108 counties was calculated. H is defined as $H = (\exp(\beta\Delta x) - 1) \times N$ where β is the national relative rate estimate for a 1-$\mu g/m^3$ increase in $PM_{10\text{-}2.5}$, Δx is 10 $\mu g/m^3$, and N is the number of hospital admissions across the 108 counties for 2005.

Within a county, levels of $PM_{10\text{-}2.5}$ are less homogeneous than for $PM_{2.5}$. To assess the potential effect of exposure measurement error, regression calibration[25] was performed for a subset of 60 counties with more than 1 pair of collocated $PM_{2.5}$ and PM_{10} monitors.

Chemical composition data for $PM_{10\text{-}2.5}$ are not available at the national level. The chemical composition of $PM_{2.5}$ differs between the eastern and western United States[9,26] and it is likely this also is true for $PM_{10\text{-}2.5}$. Therefore, the effects of $PM_{10\text{-}2.5}$ for the eastern and western United States were estimated separately. In addition, the composition of $PM_{10\text{-}2.5}$ is known to vary by degree of urbanicity,[9] but evidence indicating to what extent these compositional differences lead to different health risks is sparse. Therefore, the modification of $PM_{10\text{-}2.5}$ log RRs was explored by a county's degree of urbanicity by including the percentage of the population living in an urban area or urban cluster within a given county as a second stage covariate in the hierarchical model. An urban area is defined in the US census as a densely settled area consisting of core census block groups that have both a population density of at least 1000 people per square mile and are surrounded by census blocks that have an overall density of at least 500 people per square mile.

The sensitivity of the key findings was assessed with respect to the degrees of freedom in the smooth function of time used to adjust for seasonal and long-term trends, the lag of exposure to coarse particulate matter, and the degrees of freedom in the smooth functions of temperature and dew-point temperature.

The data were analyzed using the statistical software R version 2.6.2 (R Core Development Group). The specific code used for analyzing these data can be viewed at http://www.biostat.jhsph.edu/rr/coarse/.

RESULTS

For the 108 counties, there were 3.7 million cardiovascular disease and 1.4 million respiratory disease admissions from January 1, 1999, through December 31, 2005. Daily cardiovascular disease rates had a median of 19.7 admissions per day per 100 000 people (interquartile range [IQR], from 16.2-22.2). Daily respiratory disease rates had a median of 7.3 admissions per day per 100 000 people (IQR, 6.6-8.8). Cardiovascular and respiratory disease rates were both slightly higher in the eastern United States than in the western United States, and respiratory disease rates were slightly higher in less urban counties (TABLE 1).

Levels of $PM_{10-2.5}$ were almost twice as high in the western United States as in the eastern United States (TABLE 2). Levels of $PM_{2.5}$ displayed the opposite pattern, with the eastern states having a median level approximately 3 μg/m^3 higher than the western states.

For each pollutant, the within-county monitor-to-monitor variability of the daily concentrations was estimated by calculating the median pairwise Pearson correlations of the monitor-specific daily values and taking the median and IQR of the estimated correlations across the 108 counties. The median within-county correlations for the 108 counties were 0.92 (IQR, 0.86-0.95) for $PM_{2.5}$, 0.76 (IQR, 0.68-0.88) for PM_{10}, and 0.60 (IQR, 0.51-0.70) for $PM_{10-2.5}$, indicating greater spatial homogeneity for $PM_{2.5}$ than for $PM_{10-2.5}$. Measurement of $PM_{10-2.5}$ was not strongly correlated with $PM_{2.5}$, with a median correlation of 0.12 across counties, but a moderate correlation with PM_{10} was evident (median correlation of 0.75).

FIGURE 2 shows the national average estimates and 95% posterior intervals (PIs) of the percentage increases in cardiovascular disease admissions associated with $PM_{10-2.5}$ and $PM_{2.5}$. FIGURE 3 shows the corresponding estimates for respiratory disease admissions. Results are shown for lags 0, 1, and 2 days for single pollutant models ($PM_{10-2.5}$ and $PM_{2.5}$ are included alone in the model) and for the 2-pollutant models ($PM_{10-2.5}$ and $PM_{2.5}$ are included jointly in the model). In the 2-pollutant models, pollutants were included simultaneously at the same lag.

Table 1. Daily Hospital Admission Rates for 1999-2005 for Cardiovascular and Respiratory Diseases in 108 US Counties

	No. of Counties	Daily Hospital Admission Rates per 100 000 People, Median (IQR): Cardiovascular Disease	Respiratory Disease
All	108	19.7 (16.2-22.2)	7.3 (6.6-8.8)
Low urbanicity[a]	54	19.8 (17.3-22.0)	7.9 (6.8-9.1)
High urbanicity[b]	54	19.2 (15.7-22.5)	7.1 (6.3-8.5)
Eastern United States			
All	77	20.7 (18.9-23.5)	8.1 (7.0-9.3)
Low urbanicity[a]	37	20.4 (18.9-22.8)	8.1 (7.0-9.2)
High urbanicity[b]	40	21.2 (18.9-24.3)	8.1 (6.9-9.5)
Western United States			
All	31	15.5 (13.6-16.6)	6.5 (5.7-7.5)
Low urbanicity[a]	17	15.6 (13.6-18.7)	6.7 (5.7-8.5)
High urbanicity[b]	14	15.5 (13.9-15.8)	6.3 (5.4-6.9)

Abbreviation: IQR, interquartile range.
[a] Defined as below the median percentage of urbanicity for the 108 counties included in the data set, which is equal to 96%.
[b] Defined as above the median percentage of urbanicity for the 108 counties included in the data set, which is equal to 96%.

Unadjusted RR estimates were statistically significant for cardiovascular disease admissions only. A 10-μg/m^3 increase in $PM_{10-2.5}$ was associated with a 0.36% (95% PI, 0.05 to 0.68) increase in cardiovascular disease admissions on the same day. However, when adjusted for $PM_{2.5}$, this association was no longer statistically significant (0.25% [95% PI, −0.11 to 0.60]). The posterior probability that this RR is positive is 0.94. A 10-μg/m^3 increase in $PM_{10-2.5}$ was associated with a nonstatistically significant unadjusted 0.33% (95% PI, −0.21 to 0.86) increase in respiratory disease admissions and a nonstatistically significant 0.26% (95% PI, −0.32 to 0.84) increase in respiratory disease admissions when adjusted for $PM_{2.5}$. The unadjusted associations of $PM_{2.5}$ with cardiovascular and respiratory disease admissions were 0.71% (95% PI, 0.45 to 0.96) at lag 0 (same-day exposure) and 0.44% (95% PI, 0.06 to 0.82) at lag 2 (exposure 2 days before hospital admission) (Figure 2 and Figure 3).

There were no statistically significant differences in the regional average effects of $PM_{10-2.5}$ for either outcome (FIGURE 4). There were no significant associations of $PM_{10-2.5}$ or $PM_{2.5}$ and cause-specific cardiovascular disease and respiratory disease outcomes.

For the 108 counties, the median of the urbanicity indicator is equal to 96% (IQR, 87%-98%). The degree of urbanicity of a county positively modified the association between $PM_{10-2.5}$ at lag 0 and hospital admissions for cardiovascular disease with a posterior probability of 0.98. For each 10-μg/m^3 increment of $PM_{10-2.5}$, a county with 1% higher urbanicity with respect to another county was estimated to have an additional 0.065% (95% PI, 0.002%-0.127%) increase in risk (FIGURE 5). There was no evidence of effect modification by degree of urbanicity for the respiratory outcomes.

Table 2. Levels of $PM_{2.5}$, PM_{10}, and $PM_{10-2.5}$ for 108 US Counties From 1999-2005

	Median (IQR), μg/m^3
$PM_{2.5}$	
108 counties	13.5 (11.1-15.8)
Counties in eastern United States	13.8 (12.3-15.8)
Counties in western United States	11.1 (10.1-14.3)
PM_{10}	
108 counties	23.5 (20.6-28.6)
Counties in eastern United States	23.0 (19.9-26.3)
Counties in western United States	28.0 (21.2-36.4)
$PM_{10-2.5}$[a]	
108 counties	9.8 (6.9-15.0)
Counties in eastern United States	9.1 (6.6-13.1)
Counties in western United States	15.4 (10.3-21.8)

Abbreviations: IQR, interquartile range; $PM_{2.5}$, particulate matter is 2.5 μm or less in aerodynamic diameter; PM_{10}, particulate matter is 10 μm or less in aerodynamic diameter; $PM_{10-2.5}$, particulate matter is greater than 2.5 μm and 10 μm or less in aerodynamic diameter.
[a] Data obtained from the collocated monitor pairs of $PM_{2.5}$ and PM_{10}.

Results for $PM_{2.5}$ for a larger set of 202 counties (a subset of the 204 counties in Dominici et al[3]) were consistent with previous findings for the period 1999-2002 among the 204 counties[3] (**FIGURE 6**).

To assess the potential effect of exposure measurement error, regression calibration[25] was performed for a subset of 60 counties with more than 1 pair of collocated $PM_{2.5}$ and PM_{10} monitors. The national average associations did not show qualitative differences when measurement error was considered.

Several analyses were conducted as internal checks on the methods. The same analyses were run for hospitalizations caused by injuries and other external causes as the outcomes (*ICD-9* codes 800-849). When any unmeasured temporal confounding (number of degrees of freedom >8 per year) is aggressively removed, the national average estimate for injury is equal to zero.

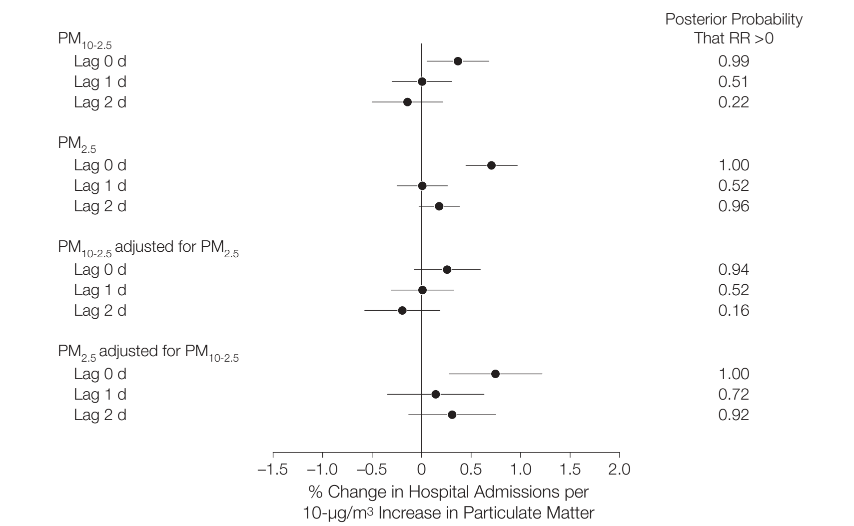
COMMENT

The NAAQS for particulate matter proposed by the US EPA in 2005 would have replaced the daily PM_{10} standard with a daily $PM_{10\text{-}2.5}$ standard, but that proposed standard was not retained in the final proposal because of a need for further evidence. Currently, national evidence concerning the health risks of short-term exposure to $PM_{10\text{-}2.5}$ is limited, although there is long-standing recognition of how size influences patterns of deposition within the respiratory tract.[1] We did not find statistically significant associations between same-day $PM_{10\text{-}2.5}$ concentration and emergency hospital admissions for cardiovascular or respiratory diseases when we adjusted for $PM_{2.5}$.

We estimated a 0.36% increase in cardiovascular disease admissions per 10-μg/m³ increase in $PM_{10\text{-}2.5}$ that although small could have public health significance. However, after adjustment for $PM_{2.5}$, the association was no longer statistically significant, suggesting either that the adverse effects of exposure to coarse particulate matter in the air are attributable to the previously demonstrated hazard of fine particulate matter, or that our study lacked sufficient statistical power to demonstrate an independent association of coarse particulate matter and emergency hospital admissions.

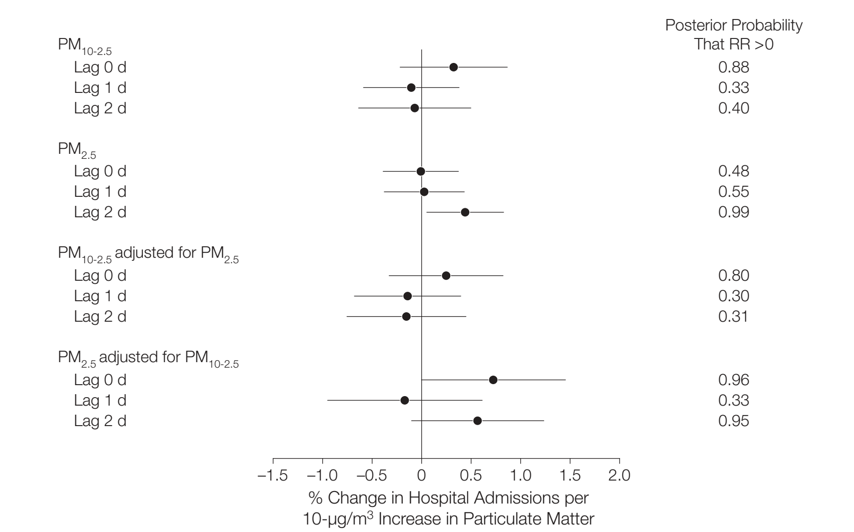
In their literature review, Brunekreef and Forsberg[5] found mixed results with strong and weak associations of coarse particulate matter with cardiovascular and respiratory disease admissions. Of the 5 studies with morbidity outcomes reviewed by Brunekreef and Forsberg,[5] 4 found positive associations; 2 were statistically significant. Ostro et al[27] found an association between coarse particulate matter and cardiovascular mortal-

Figure 2. Percentage Change in Emergency Hospital Admissions Rate for Cardiovascular Diseases per a 10-μg/m³ Increase in Particulate Matter



Estimates are on average across 108 counties. $PM_{2.5}$ indicates particulate matter is 2.5 μm or less in aerodynamic diameter; PM_{10}, particulate matter is 10 μm or less in aerodynamic diameter; $PM_{10\text{-}2.5}$, particulate matter is greater than 2.5 μm and 10 μm or less in aerodynamic diameter; RR, relative risk. Error bars indicate 95% posterior intervals.

Figure 3. Percentage Change in Emergency Hospital Admissions Rate for Respiratory Diseases per a 10-μg/m³ Increase in Particulate Matter



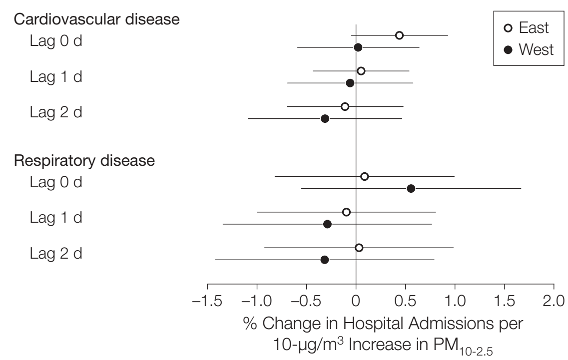
Estimates are on average across 108 counties. Error bars indicate 95% posterior intervals. RR indicates relative risk.

ity in California data, as did Burnett et al[28] in a Canadian study. Similarly, Kan et al[29] found strong associations between coarse particulate matter and cardiovascular mortality in Shanghai, China, but Host et al[30] found an opposite pattern, with coarse particulate matter having a stronger association with respiratory hospitalizations. A few studies have associated coarse particulate matter with inflammatory responses as well as with decreases in heart rate variability among susceptible people.[31-33] These studies did not report results adjusted for $PM_{2.5}$ exposure.

For the cardiovascular disease admissions, the association at lag 0 with $PM_{2.5}$ concentration is almost 3 times larger than that for $PM_{10\text{-}2.5}$ concentration in the 2-pollutant model. This finding is consistent with previous smaller studies that also found the fine fraction to be associated with greater risk per unit mass than the coarse fraction.[34,35] In the 2-pollutant model, the effect of $PM_{2.5}$ on respiratory admissions at lag 2 is also about 3 times larger than the effect of $PM_{10\text{-}2.5}$. Because of the intermittent nature of the particulate matter monitoring data, it was not possible to fit distributed lag models that estimate cumulative multiday effects. If daily data were available, the precision of single lag estimates would be increased greatly. Because the largest effects were observed at lag 0, we anticipate that the cumulative effects would be larger than the effects captured by the single-lag model used in the current study.[36-38]

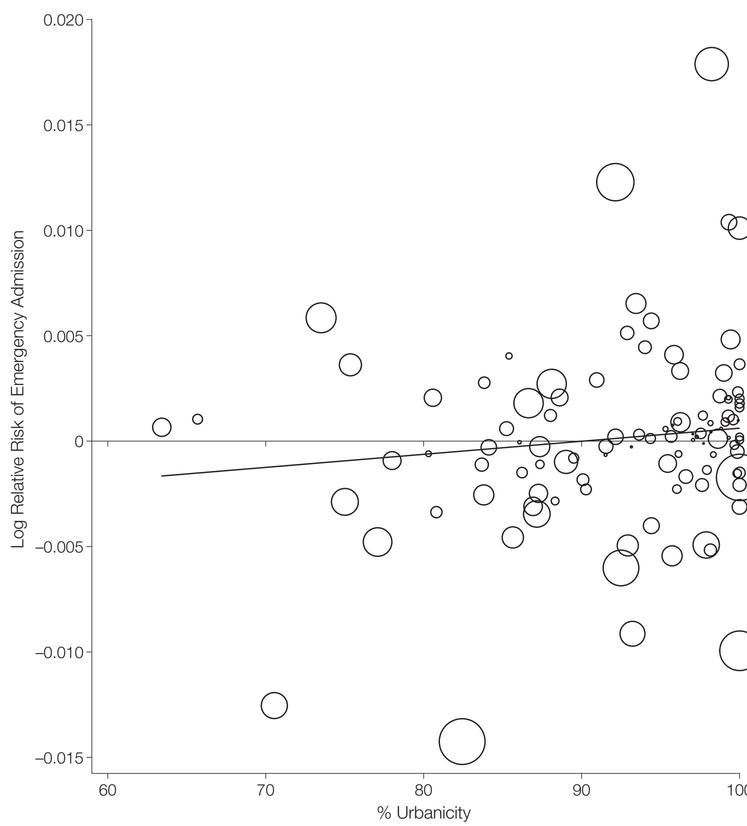
Interpretation of our findings in this study is complicated by the shared sources for particulate matter in differing size ranges. Coarse particulate matter comes primarily from processes such as mechanical grinding, windblown dust, and agricultural activities, whereas smaller particles measured as $PM_{2.5}$ are more likely to result from combustion processes. Consequently, the chemical composition of particulate matter typically differs by size with more crustal materials (eg, silicon, calcium) in coarse particulate matter and more combustion-related components (eg, sulfate, nitrate, ammonium, and carbon) in $PM_{2.5}$. However, within the coarse particulate matter size range, concentrations in urban environments generally are more influenced by transportation than in rural environments, in which agriculture, other

Figure 4. Percentage Change in Emergency Hospital Admissions Rate for Cardiovascular Diseases and Respiratory Disease per a 10-μg/m³ Increase in $PM_{10\text{-}2.5}$



Unadjusted for $PM_{2.5}$, on average across 77 counties in the eastern United States and 31 counties in the western United States. $PM_{10\text{-}2.5}$ indicates particulate matter is greater than 2.5 μm and 10 μm or less in aerodynamic diameter. Error bars indicate 95% posterior intervals.

Figure 5. County-Specific Log Relative Risks of Emergency Hospital Admissions for Cardiovascular Disease per 10-μg/m³ Increase in $PM_{10\text{-}2.5}$ at Lag 0

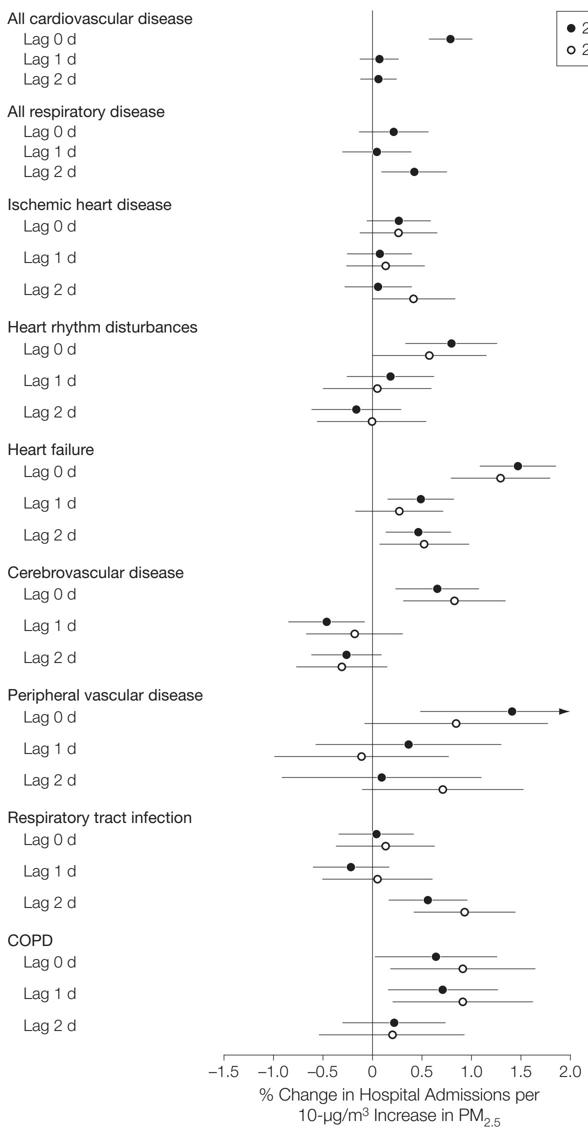


Unadjusted for $PM_{2.5}$ and plotted vs percentage of urbanicity. The curve was fit to the data using a 2-stage hierarchical model regression. The size of circles is proportional to the standard error of the estimated log relative risk. $PM_{10\text{-}2.5}$ indicates particulate matter is greater than 2.5 μm and 10 μm or less in aerodynamic diameter.

sources such as unpaved roads and construction sites, and wind are key influences.[6] In addition, while particles are often divided by size at a cutoff of 2.5 µm in aerodynamic diameter, the typical urban air distribution of particle volume follows a bimodal distribution with a breakpoint closer to 1 µm,[7,8] creating an overlap between the generating mechanisms and sources of particulate matter for the EPA size designations of $PM_{2.5}$ and $PM_{10-2.5}$.

Particle size affects atmospheric transport and deposition patterns, as evidenced by the different within-county correlations of $PM_{2.5}$ and $PM_{10-2.5}$ noted in this study. The varying sources of particulate matter in urban and rural locations can result in dissimilar chemical compositions in these 2 settings.

Figure 6. Percentage Change in Emergency Hospital Admissions Rate for Cardiovascular Diseases per a 10-µg/m³ Increase in $PM_{2.5}$



On average across 202 US counties (a subset of the 204 counties reported by Dominici et al[3]) with a population larger than 200 000 for 1999-2005. Estimates reported by Dominici et al[3] for both emergency and elective hospitalizations for 204 counties and for the period 1999-2002 are denoted by empty dots. COPD indicates chronic obstructive pulmonary disease; $PM_{2.5}$, particulate matter is 2.5 µm or less in aerodynamic diameter. Error bars indicate 95% posterior intervals.

We have investigated whether the degree of urbanicity of a county modifies the health effects of $PM_{10-2.5}$ by using the census urbanicity indicator. Studies at individual locations with high coarse particulate matter levels have suggested that rural coarse particulate matter consisting of natural crustal materials poses a lesser health risk than urban coarse particulate matter.[27,39] In addition, limited compositional data on coarse particulate matter have indicated that urban coarse particulate matter tends to be enriched by constituents not typically found in rural coarse particles.[40] While our results indicate that urbanicity does modify the health risk of $PM_{10-2.5}$, most of the counties in this study had large urban populations. The minimum value of the census urbanicity indicator over the 108 counties was 63%. Therefore, it is likely that the range of census urbanicity in this study does not reflect the full range of urban and rural coarse particulate matter in the United States.

Several challenges face researchers in estimating the health risks of $PM_{10-2.5}$. Because $PM_{10-2.5}$ levels typically are more spatially heterogeneous than $PM_{2.5}$ due to shorter residence times in the atmosphere for these higher mass particles, the potential for exposure measurement error in epidemiological studies based on central monitors is likely to be greater for investigating associations of health indicators with $PM_{10-2.5}$ than with $PM_{2.5}$. We did not find qualitative differences in the national average estimate when measurement error was considered using a regression calibration approach.

Additionally, the monitoring of PM_{10} is decreasing over time, thereby reducing the number of locations where $PM_{10-2.5}$ can be estimated. Because of the increasing monitoring of $PM_{2.5}$ from 1999 to 2002 (in addition to the existing monitoring of PM_{10}), the number of days with $PM_{10-2.5}$ measurements increased by 30%. After 2002, because of the decline in monitoring PM_{10}, the number of days with available $PM_{10-2.5}$ measurements decreased by 45%. The current study found no statistically significant association at the national level of cardiovascular risk and ambient exposure to coarse particulate matter. Nevertheless, we recommend that these findings be considered when the NAAQS for particulate matter is next reviewed, and that the monitoring of PM_{10} continue so that further studies can be performed.

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Study concept and design: Peng, Bell, Zeger, Samet, Dominici.
Acquisition of data: Bell, McDermott.
Analysis and interpretation of data: Peng, Chang, Bell, Zeger, Dominici.
Drafting of the manuscript: Peng, Chang, Bell, Samet, Dominici.
Critical revision of the manuscript for important intellectual content: Peng, Bell, McDermott, Zeger, Samet, Dominici.
Statistical analysis: Peng, Chang, Bell, McDermott, Zeger, Dominici.
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