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Triggering of cardiovascular hospital admissions by fine particle concentrations in New York state: Before, during, and after implementation of multiple environmental policies and a recession☆

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A R T I C L E I N F O

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A B S T R A C T

Background: Previous studies reported triggering of acute cardiovascular events by short-term increasedPM$_{2.5}$ concentrations. From 2007 to 2013, national and New York state air quality policies and economic influences resulted in reduced concentrations of $PM_{2.5}$ and other pollutants across the state. We estimated the rate of cardiovascular hospital admissions associated with increased $PM_{2.5}$ concentrations in the previous 1–7 days, and evaluated whether they differed before (2005–2007), during (2008–2013), and after these concentration changes (2014–2016).

Methods: Using the Statewide Planning and Research Cooperative System (SPARCS) database, we retained all hospital admissions with a primary diagnosis of nine cardiovascular disease (CVD) subtypes, for residents living within 15 miles of $PM_{2.5}$ monitoring sites in Buffalo, Rochester, Albany, Queens, Bronx, and Manhattan from 2005 to 2016 (N = 1,922,918). We used a case-crossover design and conditional logistic regression to estimate the admission rate for total CVD, and nine specific subtypes, associated with increased $PM_{2.5}$ concentrations.

Results: Interquartile range (IQR) increases in $PM_{2.5}$ on the same and previous 6 days were associated with 0.6%–1.2% increases in CVD admission rate (2005–2016). There were similar patterns for cardiac arrhythmia, ischemic stroke, congestive heart failure, ischemic heart disease (IHD), and myocardial infarction (MI). Ambient $PM_{2.5}$ concentrations and annual total CVD admission rates decreased across the period. However, the excess rate of IHD admissions associated with each IQR increase in $PM_{2.5}$ in previous 2 days was larger in the after period (2.8%; 95%CI = 1.5%–4.0%) than in the during (0.6%; 95% CI = 0.0%–1.2%) or before periods (0.8%; 95%CI = 0.2%–1.3%), with similar patterns for total CVD and MI, but not other subtypes.

Conclusions: While pollutant concentrations and CVD admission rates decreased after emission changes, the same $PM_{2.5}$ mass was associated with a higher rate of ischemic heart disease events. Future work should confirm these findings in another population, and investigate whether specific PM components and/or sources trigger IHD events.

1. Introduction

Previously, we and others have reported that short-term increases in ambient fine particle concentrations were associated

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with triggering of acute cardio- and cerebrovascular events, including myocardial infarction (Mustafić et al., 2012; Pope et al., 2015), ischemic stroke (Shah et al., 2015), cardiac arrhythmia (Link et al., 2013; Peters et al., 2000; Rich et al., 2006a, 2005; 2006b), and heart failure (Shah et al., 2018). For example, in Rochester, New York, each 7.1 μg/m^3 increase in $PM_{2.5}$ in the previous hour was associated with an 18% increase in the risk of a ST-elevation myocardial infarction ($OR = 1.18$; 95% $CI = 1.01, 1.38$) (Gardner et al., 2014). Others have reported similar findings (Akbarzadeh et al., 2018; Argacha et al., 2016; Liu et al., 2018; Pope et al., 2015; Zhang et al., 2016).

Since the early-to mid-2000s, policy initiatives to improve air quality have been implemented nationally and across New York State (NYS). These initiatives include use of ultra-low sulfur on-road diesel fuel starting in October 2006, the requirement for particle regenerative traps on new heavy-duty diesel on-road trucks and buses on July 1, 2007, the requirement for NOx control as of January 1, 2010, decreases in the sulfur content of non-road diesel fuel between 2007 and 2014, and the requirement that all No. 2 based fuels sold in NYS be ultra-low sulfur by July 1, 2012. Additionally, several actions (e.g. emission control technology retrofits in the Ohio River Valley, Cross-State Air Pollution Rule, and electricity policy changes in Ontario) have occurred during this same time to reduce SO_2 and NOx emissions from power plants in upwind source areas. During this period, there were also major economic drivers of changes in air quality including the 2008 recession and the change in the price of natural gas compared to coal and oil (Squizzato et al., 2018).

Squizzato et al. (2018) reviewed the spatial and temporal patterns of all the gaseous pollutants and particulate matter measurements made between 2005 and 2016 at every New York State Department of Environmental Conservation (NYS DEC) site in NYS. Not all pollutants are measured at every site. They reported that $PM_{2.5}$ concentrations decreased significantly at all sites for which there are data (−2.2% per year to −8.6% per year across sites). Similarly, SO_2 concentrations dropped significantly at all sites within this period, with the highest reductions observed at the urban sites (e.g., −8.5% per year at Queens, New York City). Reductions in NOx emissions contributed to the reduction in high ozone episodes during summers. However, no reductions were found for the maximal spring ozone concentrations across the state. There were observed increases in autumn and winter ozone concentrations (e.g., $6.6 \pm 0.4\%$ per year across New York City). Thus, the decrease in $PM_{2.5}$ and inorganic precursor gases (SOx and NOx) in Rochester (Emami et al., 2018) and all of NYS over the past 12 years (Squizzato et al., 2018) suggest that the composition of $PM_{2.5}$ has likely changed during this period. Thus, whether these PM composition changes affected the rate of acute cardiovascular events associated with increased ambient $PM_{2.5}$ concentrations may provide clues as to the PM sources/mixtures that most strongly trigger acute cardiovascular events.

Using the New York State Department of Health Statewide Planning and Research Cooperative System (SPARCS), a legislatively mandated database of NYS hospital discharges, and daily ambient $PM_{2.5}$ measurements made at multiple monitoring sites across NYS, we examined the association between short-term increases in $PM_{2.5}$ concentration and hospital admissions for acute cardiovascular events across NYS. We then evaluated whether that relative rate differed before (2005–2007), during (2008–2013), and after (2014–2016) these environmental policies/actions were implemented and economic impacts occurred. We hypothesized that short-term increases in $PM_{2.5}$ concentrations would be associated with an increased rate of total and cause-specific cardiovascular outcomes. We also hypothesized that these relative rates would be smaller after implementation of these environmental actions and policies, the influence of the recession and cost-driven changes in the fuel used for electricity generation, and the resulting reductions in $PM_{2.5}$ and most other pollutant concentrations across the state.

2. Materials and methods

2.1. Study population and hospital admissions data

Information on hospital admissions were obtained from the inpatient SPARCS database, which we have used previously (Fitzgerald et al., 2014; Garcia et al., 2011; Jones et al., 2013, 2015, Lin et al., 2012, 2016, 2004, 2005, 2008a, 2008b, 2009, 2010). SPARCS is a legislatively mandated database that covers ~95% of hospitals in NYS, excluding federal facilities (e.g. Veterans Affairs Hospitals) and psychiatric facilities. It contains billing and medical information on over 2.5 million discharges for NYS hospitals, 1.5 million ambulatory surgery center visits, and 6.5 million emergency department visits per year. SPARCS data include patient information on the principal diagnoses and up to 24 other diagnoses at the time of hospital admission, as well as demographic characteristics and event/hospital information including date of birth, gender, race, ethnicity, street address, admission date, source of payment, and length of stay. Data reported by hospitals are reviewed by SPARCS administrative staff for accuracy and completeness. We geocoded the residential address for each hospitalization using the Street and Address Maintenance Program in ArcGIS 10.3.1 (The NYS GIS Program Office, 2017).

We retained those hospital admissions with a "principal" diagnoses of cardiovascular disease (defined using ICD-9 and ICD-10 codes) and an admission date from January 1, 2005 to December 31, 2016, for adult (≥18 years of age) residents of NYS. From this primary diagnosis, we defined total cardiovascular disease as ICD-9 = 393–396, 401–405, 410–415, 427–428, 430–434, 436–438, and ICD-10 = I05-I08, I10-I16, I20-I25, I47-I49, I42, I50-I51, I60-I69, I26-I27. In a similar manner, we defined cardiac arrhythmias (ICD-9 = 427 and ICD-10 = I47-I49), cerebrovascular disease (ICD-9 = 430–434 and 436–438 and ICD-10 = I60-I69), chronic rheumatic heart disease (ICD-9 = 393–396 and ICD-10 = I05-I08), congestive heart failure (ICD-9 = 428 and ICD-10 = I42 and I50-I51), hypertension (ICD-9 = 401–405 and ICD-10 = I10-I16), ischemic heart disease (ICD-9 = 410–414 and ICD-10 = I20-I25), myocardial infarction (ICD-9 = 410 and ICD-10 = I21), and ischemic stroke (ICD-9 = 434 and ICD-10 = I63). We then excluded all study subjects living more than 15 miles from any our six $PM_{2.5}$ monitoring sites in Buffalo, Rochester, Albany, Bronx, Manhattan, and Queens (described below), leaving N = 1,922,918 available for analysis. This study was reviewed and approved by the Institutional Review Board at the State University of New York at Albany.

For use in descriptive analyses, we estimated the population size within each 15-mile buffer around a monitoring station (for 18 age and 8 race categories for males and females separately) for each day during the study period, using population size estimates from each census tract within the 2000 and 2010 Census data and the 2011–2015 American Community Survey. For those census tracts not completely within the buffer, we scaled the population size from that census tract by the proportion of the census tract within the buffer. We then estimated the population size for each day by linear interpolation between the 2000 and 2010 Census and between the 2010 Census and 2011–2015 American Community Survey data; this latter trend was extrapolated until December 2016. The spatial analyses of census tracts were performed using ArcGIS 10.4.1 (ESRI), with linear interpolations computed using R 3.4.0 (https://www.r-project.org/).