American Journal of Epidemiology Advance Access published July 30, 2009

American Journal of Epidemiology
Published by the Johns Hopkins Bloomberg School of Public Health 2009. DOI: 10.1093/aje/kwp165

## Original Contribution

# Lack of Association Between Estimated World Trade Center Plume Intensity and Respiratory Symptoms Among New York City Residents Outside of Lower Manhattan

**Robert J. Laumbach, Gerald Harris, Howard M. Kipen, Panos Georgopoulos, Pamela Shade, Sastry S. Isukapalli, Christos Efstathiou, Sandro Galea, David Vlahov, and Daniel Wartenberg**

*Initially submitted December 15, 2008; accepted for publication May 15, 2009.*

Researchers have reported adverse health effects among rescue/recovery workers and people living near the World Trade Center on September 11, 2001. The authors investigated the occurrence of respiratory symptoms among persons living outside of Lower Manhattan in areas affected by the World Trade Center particulate matter plume. Using a novel atmospheric dispersion model, they estimated relative cumulative plume intensity in areas surrounding the World Trade Center site over a 5-day period following the collapse of the buildings. Using data from a telephone survey of residents ($n = 2,755$) conducted approximately 6 months after the event, the authors evaluated associations between the estimated plume intensities at individual residence locations and self-reported respiratory symptoms among nonasthmatics, as well as symptoms and nonroutine care among asthmatics. Comparing persons at or above the 75th percentile of cumulative plume intensity with those below it, there was no statistically significant difference in self-reported new-onset wheezing/cough after September 11 (16.1% vs. 13.3%; adjusted odds ratio = 1.0, 95% confidence interval: 0.7, 1.7) and no worsening of asthma from before September 11 to the 4 weeks prior to the survey (13.9% vs. 16.6%; odds ratio = 1.0, 95% confidence interval: 0.3, 2.8). These results suggest that the plume was not strongly associated with respiratory symptoms outside of Lower Manhattan, within the limitations of this retrospective study.

air pollution; asthma; inhalation exposure; New York City; particulate matter; respiratory tract diseases; September 11 terrorist attacks

Abbreviations: CI, confidence interval; WTC, World Trade Center.

Dust and smoke created by the destruction of the World Trade Center (WTC) in New York City on September 11, 2001 (9/11) initially engulfed the site and its vicinity in Lower Manhattan. While the impact was most graphic and intense at ''Ground Zero,'' aerial photographs and other observations demonstrated that airborne emissions extended well beyond the immediate vicinity of Ground Zero. Over several days following the event, the plume of air contaminants spread to parts of Brooklyn and New Jersey, as well as other areas in Manhattan, shifting with changing wind direction and eventually extending into Westchester and areas farther away on Long Island. On September 14, rain washed out most of the remaining particles.

In this study, we assessed a possible association with increased respiratory symptoms among persons living outside of Lower Manhattan who were exposed to the WTC plume. We used results from a simulated plume intensity model to estimate individual residential exposures, because no measurements of ambient air quality were taken in the vicinity of Ground Zero in the days immediately following 9/11. Particulate matter concentrations at several other Lower Manhattan sites were elevated above normal background levels, but these sites were not located directly

Correspondence to Dr. Robert Laumbach, Environmental and Occupational Medicine, University of Medicine and Dentistry of New Jersey–Robert Wood Johnson Medical School, 170 Frelinghuysen Road, Piscataway, NJ 08854 (e-mail: laumbach@eohsi.rutgers.edu).

in the path of the plume (1). In the absence of direct measurements, previous investigators developed a novel atmospheric dispersion model that combined numerical modeling and ground- and space-based observations to reconstruct the path and intensity of the plume from the WTC site (2–4). In the present study, we used this model to estimate relative plume intensities in locations throughout the region.

Health effects from exposure to dust and other emissions from the WTC site have been demonstrated most readily among firefighters and other rescue and recovery workers, who probably had the highest exposures. For example, firefighters exhibited increased coughing with bronchial hyperreactivity (5, 6), as well as sarcoid-like pulmonary disease (7). Other WTC responders exhibited increased respiratory symptoms and abnormal pulmonary function (8).

New York City residents exposed to the plume, most of whom had substantially lower exposures than the rescue workers, have not been studied in as much detail as the rescue and recovery workers. In a survey of Manhattan residents living south of 110th Street, 27% of 134 respondents previously diagnosed with asthma reported worsening of symptoms since 9/11 (9). A review of charts of 205 pediatric asthma patients at a Lower Manhattan clinic found that numbers of clinic visits and medication prescriptions were greater during the year following 9/11 than during the year before 9/11 (10). A survey of enrollees in a managed-care plan found that residence in Lower Manhattan or western Brooklyn was associated with self-reported worsening asthma after 9/11 (11). Similarly, nonasthmatic residents of buildings close to Ground Zero reported statistically significantly more new-onset and persistent new-onset respiratory symptoms than residents of buildings several miles away in Upper Manhattan (12, 13). However, these studies had significant limitations, including lack of an objective measure of exposure to the WTC plume and a low participation rate in the latter 2 studies.

In this study, to evaluate the impact of the WTC plume on residents living outside of Lower Manhattan, we used data from a representative population sample surveyed by telephone and modeled estimates of WTC plume intensity by space and time. We assessed whether measures of estimated plume intensity in neighborhoods of respondents were associated with new-onset and worsening respiratory symptoms among subjects with and without previous diagnoses of asthma.

## MATERIALS AND METHODS

### Study population

Our study subjects were respondents to a random digit dialing household survey of self-reported respiratory symptoms and related health-care utilization conducted between March 25 and June 25, 2002, approximately 6 months after the WTC disaster. Sampling and collection methods have been described elsewhere (14, 15). The sampling frame included all adults residing in the New York City metropolitan area on 9/11, from which equal numbers of people were sampled from 4 geographic zones radiating out from the WTC site. A total of 2,755 persons were interviewed. The overall cooperation rate was 56%. To address concerns about likely biases associated with close proximity of residence to Ground Zero (discussed below), we excluded residents of Manhattan south of 14th Street (about 3 km north of Ground Zero), the area defined in the survey as closest to the WTC, from most of our analyses. Additionally, we excluded 33 subjects who reported being involved at the WTC site as emergency, construction, or health-care personnel, thus retaining 1,810 out of 2,755 persons.

### Survey methods

All interviews were conducted by trained interviewers, who used a computer-assisted telephone interview system and a structured questionnaire. Interviews were available in English, Spanish, and Chinese. The institutional review boards of the New York Academy of Medicine and the University of Medicine and Dentistry of New Jersey reviewed and approved the study, and all study subjects provided verbal consent at the time of the interview.

We used a series of questions to assess respiratory symptoms prior to 9/11 and prior to the survey (15). Subjects were classified as asthmatic if they responded ''yes'' to the question, ''Has a doctor ever told you that you have asthma?'' Subjects who denied a diagnosis of asthma prior to 9/11 were considered to have new-onset respiratory symptoms if they answered ''yes'' to the following questions: ''In the past 12 months, have you had wheezing or whistling in the chest or have you been bothered by coughing, apart from a cold or respiratory infection?'' and ''Did the problem start after September 11, 2001?'' Consistent with the approach of Reibman et al. (13), new-onset respiratory symptoms were considered to be persistent if the subject's answer was 8 or more in response to the question, ''In the past 4 weeks (28 days), how many days did you have this problem?'' Subjects who reported having received a physician's diagnosis of asthma prior to 9/11 were also asked how they would describe their asthma (1 = no symptoms, 2 = mild, 3 = moderate, 4 = severe). Worsening of asthma symptoms was defined as having moderate-to-severe symptoms during the 4 weeks prior to the survey as compared with having no symptoms or mild symptoms during the 4 works before 9/11, consistent with the definition of Fagan et al. (9). Subjects with asthma were classified as needing nonroutine medical care for asthma since 9/11 if they answered ''yes'' to any portion of a 3-part question: ''Since the WTC disaster: 1) have you gone to a hospital emergency room for asthma symptoms?; 2) have you had to stay overnight in the hospital due to your asthma?; 3) have you had to make an unscheduled visit to a doctor or health-care provider for your asthma?'' Additionally, subjects were asked whether they had experienced ''difficulty breathing because of smoke and debris during the event.'' We also elicited information about sociodemographic characteristics (age, sex, race/ethnicity, annual household income, education, marital status, and smoking).

### Cumulative plume intensity estimates

To obtain relative potential exposure intensities for this study, we simulated the plume generated by the collapse of the WTC buildings and the subsequent fires at the site. We used the Regional Atmospheric Modeling System/Hybrid Particle and Concentration Transport model to reconstruct the atmospheric dispersion of ''generic'' particulate matter on the basis of a triple-nested modeling domain of 4- × 4-km (grid 1), 1- × 1-km (grid 2), and 250- × 250-m (grid 3) resolutions, all centered at the WTC. Details on the plume reconstruction have been presented elsewhere (3). The results for the ground layer ranging from 0 m to 20 m in height were averaged to produce 8-hour particulate matter concentrations for the geographic areas included in the household telephone survey and incorporated a source decay factor that matched the observed plume intensity. This decay factor was empirical and was used to account for the decrease in the intensity of the fires and other emission sources during the days after 9/11. Because most remaining dust was settled and/or washed away by rain on September 14, which also diminished the intensity of the fires and the associated plume, we used the sum of the first 15 8-hour periods (120 hours total) following 9:00 a.m. on 9/11 as the cumulative plume intensity estimate for our analyses. These intensity estimates were calculated for each grid cell in the modeling study area. Although fires continued to burn for many days afterwards, their contribution to the estimated cumulative plume intensity was negligible, as observed from aerial images of the plume.

Cumulative residential plume intensity estimates were assigned to telephone survey participants on the basis of address for persons who lived in New York City on September 11, 2001. The assigned plume intensity was based on the value of the grid cell that covered the residence location. Respondents who lived outside of New York City on that date were assigned a plume intensity estimate corresponding to the center of the town they lived in. The 5-day cumulative relative plume intensity at the location of residence was used as a proxy for exposure, since no time-activity data were available for survey participants.

Figure 1 shows the cumulative distribution of individually assigned plume intensities. We focused on residents living outside of Lower Manhattan and classified subjects as exposed if their plume intensity was greater than or equal to the 75th percentile of the distribution. The cutpoint at the upper quartile was an arbitrary, a priori selection given that plume intensity estimates were based on a relative scale. Sensitivity analyses showed essentially similar results at higher and lower cutpoints.

### Statistical methods

To characterize the study population, we cross-tabulated exposure status with the demographic variables (age, sex, education, race/ethnicity, smoking status in the last 12 months, and total combined household income in the last year before the survey) for subjects living outside of Lower Manhattan. We assessed the comparability of the exposed

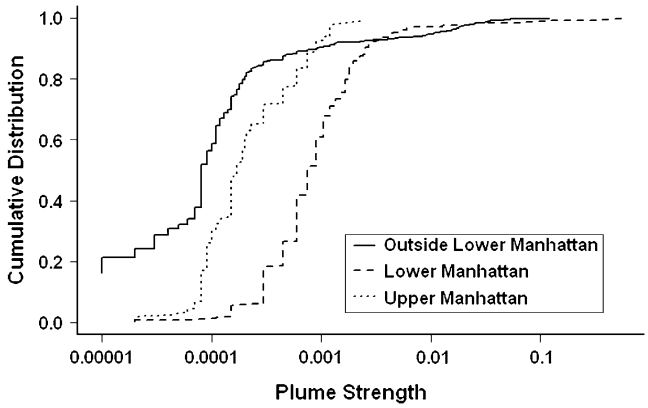


**Figure 1.** Cumulative probability of the estimated intensity of particulate matter concentrations in the World Trade Center plume over New York City following the September 11, 2001, attack, by geographic area. Cumulative probability for plume strength (estimated cumulative plume intensity) at survey participants' residential locations in the 3 regions was used in analyses of associations between plume intensity and respiratory symptom outcomes. Plume strength is expressed in relative, dimensionless units.

(at or above 75th percentile) and unexposed (below 75th percentile) populations by comparing their sociodemographic and behavioral data using Wald's $\chi^2$ test. Given that persons with a self-reported previous diagnosis of asthma were likely to respond differently to the plume than persons without that diagnosis, we conducted separate analyses for these groups.

We used logistic regression to quantify the strength of the associations between plume intensity and new-onset wheezing/coughing and persistent new-onset wheezing/coughing in nonasthmatics and worsening of asthma symptoms in asthmatics. Odds ratios and 95% confidence intervals are reported. These models included adjustment for age, sex, education, race/ethnicity, smoking status, marital status, and income. All analyses were performed on weighted data, except for reporting the raw count data. Weights were selected to account for oversampling and possible sample selection biases (see Galea et al. (14)). SAS software (SAS Institute Inc., Cary, North Carolina) was used for all analyses.

## RESULTS

### Demographic factors

Demographic data for survey respondents, excluding those living in Lower Manhattan, are presented in Table 1. Among nonasthmatics, the exposed were more likely than the unexposed to report difficulty breathing because of smoke and debris during the event, tended to have lower incomes, and were more likely to be college graduates. Among residents in these areas who reported a previous diagnosis of asthma, we found a statistically significant difference in smoking status, with nonsmokers being much more likely to be exposed than smokers.

**Table 1.** Demographic Characteristics of Survey Participants Residing in Areas Near the Site of the World Trade Center Collapse on September 11, 2001, by Exposure Status[a] and Asthma Status, Spring 2002

| | Nonasthmatics | | | | Asthmatics | | | |
|---|---|---|---|---|---|---|---|---|
| | Exposed, % ($n$ = 434) | Unexposed, % ($n$ = 1,170) | $\chi^2$ | *P* Value | Exposed, % ($n$ = 69) | Unexposed, % ($n$ = 169) | $\chi^2$ | *P* Value |
| Age, years | | | 0.68 | 0.71 | | | 1.07 | 0.59 |
| <34 | 39.8 | 37.3 | | | 38.7 | 46.0 | | |
| 35–54 | 37.6 | 40.1 | | | 36.7 | 35.5 | | |
| ≥55 | 22.6 | 22.6 | | | 24.5 | 18.4 | | |
| Sex | | | 0.15 | 0.70 | | | 1.43 | 0.23 |
| Male | 46.0 | 47.3 | | | 28.9 | 38.6 | | |
| Female | 54.0 | 52.7 | | | 71.1 | 61.4 | | |
| Education | | | 3.80 | 0.05 | | | 0.31 | 0.58 |
| Less than college graduation | 63.5 | 57.1 | | | 56.5 | 61.1 | | |
| College graduation or more | 36.5 | 42.9 | | | 43.5 | 38.9 | | |
| Race/ethnicity | | | 3.52 | 0.06 | | | 0.22 | 0.64 |
| White | 48.7 | 55.3 | | | 55.3 | 51.3 | | |
| Other | 51.3 | 44.7 | | | 44.7 | 48.7 | | |
| Smoker (last year) | | | 0.28 | 0.60 | | | 6.09 | 0.01 |
| Yes | 27.1 | 25.5 | | | 14.6 | 31.4 | | |
| No | 72.9 | 74.5 | | | 85.4 | 68.6 | | |
| Marital status | | | 2.88 | 0.09 | | | 0.09 | 0.77 |
| Never married | 34.5 | 29.1 | | | 34.3 | 36.7 | | |
| Other | | 65.5 | 70.9 | | 65.7 | 63.3 | | |
| Difficulty breathing[b] | | | 29.36 | <0.01 | | | 2.99 | 0.08 |
| Yes | 20.7 | 8.6 | | | 29.1 | 16.9 | | |
| No | 79.3 | 91.4 | | | 70.9 | 83.1 | | |
| Income (previous year) | | | 17.26 | <0.01 | | | 0.00 | 0.95 |
| <$50,000 | 61.3 | 45.6 | | | 48.1 | 48.7 | | |
| ≥$50,000 | 38.7 | 54.4 | | | 51.9 | 51.3 | | |

[a] The exposed group was defined as all survey participants living outside of Lower Manhattan (asthmatics and nonasthmatics combined) in areas with estimated cumulative plume intensities (particulate matter concentrations) at or above the 75th percentile. The unexposed group consisted of all remaining subjects.

[b] Did the respondent have difficulty breathing because of smoke and debris during the event?

### Cumulative estimated plume intensities

Figure 1 shows the cumulative probability of relative plume intensity in Lower Manhattan (at or below 14th Street), Upper Manhattan (above 14th Street), and all survey areas outside of Lower Manhattan. Residents outside of Lower Manhattan showed the greatest variability of relative residential plume intensities. The plume intensities were generally higher in Lower Manhattan than in the other areas, with a median intensity that was nearly an order of magnitude greater than those in Upper Manhattan and areas outside of Lower Manhattan. Nevertheless, the 90th percentile plume intensity for areas outside of Lower Manhattan was similar to that for Lower Manhattan, indicating that after exclusion of Lower Manhattan from some of our analyses, many of the most highly exposed survey participants remained in the analyses. Mapping of the relative cumulative plume intensity in areas excluding Lower Manhattan showed that the 75th and 90th percentile exposures among residents within this geographic area were predominantly in the western half of Brooklyn (Figure 2). In Brooklyn, plume intensities at the 75th and 90th percentile levels did not appear to be correlated with distance from the WTC, whereas in Manhattan higher intensities generally were found in close proximity to the WTC. Figure 3 shows the locations of residential addresses of subjects in the exposed (≥75th percentile) and unexposed (<75th percentile) groupings, which were used in the main analyses, in areas surrounding the WTC site excluding Manhattan.

### Survey results

In our survey data, we found no statistically significant difference in odds of new-onset wheezing/coughing since

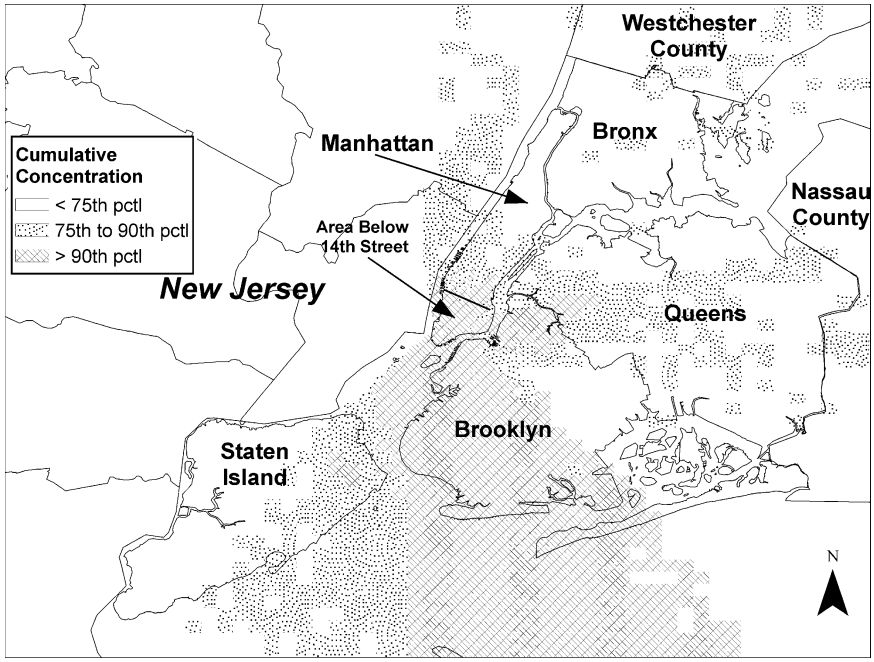


**Figure 2.** Residential cumulative particulate matter concentrations in the World Trade Center plume in the vicinity of Ground Zero following the September 11, 2001, attack. The geographic distributions of modeled grid cells with cumulative relative plume intensity concentrations below the 75th percentile (pctl), within the 75th–90th percentiles, and above the 90th percentile are shown. The relative plume intensity values for these percentile groupings were 0–0.00017, >0.00017–0.00060, and >0.00060–0.11, respectively.

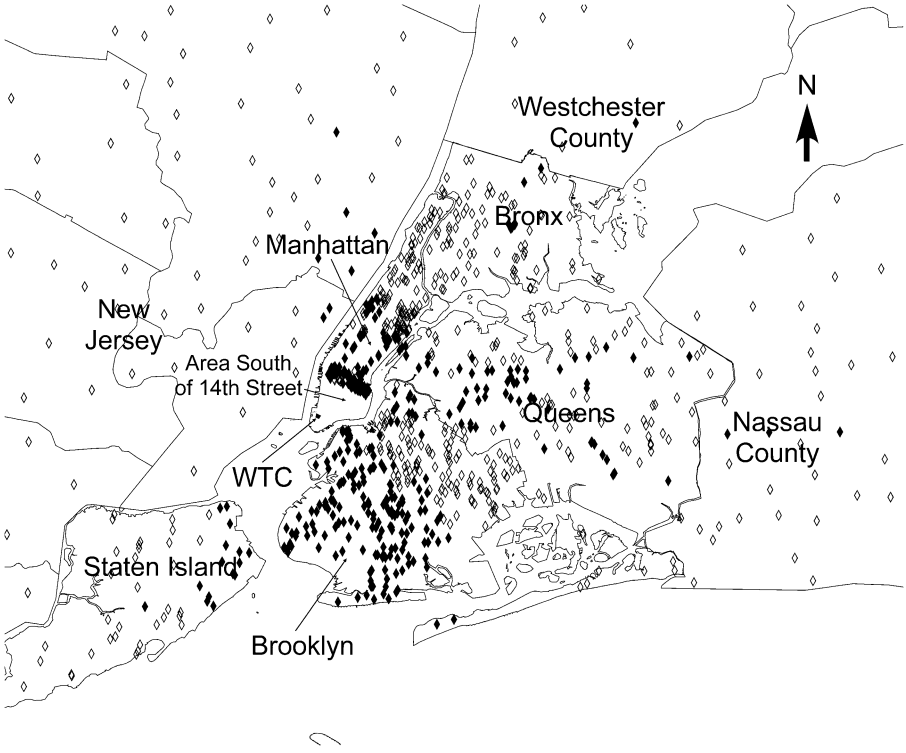


**Figure 3.** Residential locations of survey participants in areas near the site of the World Trade Center collapse on September 11, 2001. Locations with estimated cumulative plume intensities (particulate matter concentrations) greater than or equal to the 75th percentile and less than the 75th percentile are designated by solid diamonds and open diamonds, respectively.

**Table 2.** Incidence of Wheeze/Cough and Worsening of Asthma Symptoms Among Persons Residing in the Vicinity of the World Trade Center Collapse (Excluding Lower Manhattan) on September 11, 2001, by Exposure Location, Spring 2002

| Asthma Status and Outcome | Exposed[a], % | Unexposed, % | Crude OR | 95% CI | Adjusted OR[b] | 95% CI |
|---|---|---|---|---|---|---|
| Nonasthmatics | ($n = 411$) | ($n = 1,130$) | | | | |
| New-onset symptoms (wheeze/cough) | 16.1 | 13.3 | 1.3 | 0.8, 1.9 | 1.0 | 0.7, 1.7 |
| Persistent new-onset symptoms | 5.6 | 4.6 | 1.2 | 0.6, 2.3 | 1.1 | 0.5, 2.3 |
| Asthmatics | ($n = 66$) | ($n = 161$) | | | | |
| Worsening of asthma symptoms | 13.9 | 16.6 | 0.8 | 0.3, 2.0 | 1.0 | 0.3, 2.8 |
| Increase in nonroutine asthma care | 25.1 | 35.1 | 0.6 | 0.3, 1.3 | 0.5 | 0.2, 1.4 |

Abbreviations: CI, confidence interval; OR, odds ratio.
[a] Locations with cumulative relative plume intensities at or above the 75th percentile.
[b] Odds ratio adjusted for age, sex, education, race/ethnicity, smoking status, marital status, and income.

9/11 or persistent new-onset wheezing/coughing among nonasthmatic residents who had cumulative residential exposures at or above 75th percentile compared with the remaining subjects (Table 2). There also was no statistically significant difference among asthmatic responders in reporting worsening asthma or nonroutine asthma care since 9/11 when we compared those with residential exposures at or above the 75th percentile with those with exposures below the 75th percentile.

To assess the comparability of our study with other, similar studies that focused on Manhattan residents and used distance from Ground Zero as a proxy for exposure (9, 12, 13), we compared persons living in Lower Manhattan at or below 14th Street with those living above 14th Street (Table 3). Among nonasthmatic respondents, we found statistically significant adjusted odds ratios for new-onset cough/wheeze (odds ratio = 1.9, 95% confidence interval (CI): 1.1, 3.5) and persistent new-onset cough/wheeze (odds ratio = 2.5, 95% CI: 1.1, 5.9). Among asthmatics, we found no statistically significant increased risk of self-reported asthma worsening or nonroutine asthma care when comparing Lower Manhattan with Upper Manhattan (Table 3).

We conducted 2 additional sensitivity analyses. Among Manhattan residents only, we found that higher exposure to the plume (at or above the 75th percentile) was not statistically significantly associated with increased new-onset or persistent new-onset cough/wheeze, but results from analyses using the 90th and 95th percentiles were statistically significantly associated (data not shown). When analysis was limited to residents of Brooklyn, where the range of plume exposures was also broad, we also did not see a statistically significant increase in new-onset respiratory symptoms at any of these percentile cutoffs (data not shown).

## DISCUSSION

Our goal in this study was to assess whether the WTC plume was associated with increased respiratory symptoms among residents of New York City living beyond Lower Manhattan. This study is the first we know of to have

**Table 3.** Incidence of Wheeze/Cough and Worsening of Asthma Symptoms Among Persons Residing in Lower Manhattan (At or Below 14th Street) Versus Upper Manhattan (Above 14th Street) on September 11, 2001, Spring 2002

| Asthma Status and Outcome | Lower Manhattan, % | Upper Manhattan, % | Crude OR | 95% CI | Adjusted OR[a] | 95% CI |
|---|---|---|---|---|---|---|
| Nonasthmatics | ($n = 498$) | ($n = 169$) | | | | |
| New-onset symptoms (wheeze/cough) | 24.9 | 15.9 | 1.8 | 1.1, 2.9 | 1.9 | 1.1, 3.5 |
| Persistent new-onset symptoms | 10.0 | 5.3 | 2.0 | 0.9, 4.4 | 2.5 | 1.1, 5.9 |
| Asthmatics | ($n = 82$) | ($n = 31$) | | | | |
| Worsening of asthma symptoms | 17.6 | 21.8 | 0.8 | 0.2, 2.4 | 0.4 | 0.05, 2.8 |
| Increase in nonroutine asthma care | 28.8 | 30.2 | 0.9 | 0.3, 2.5 | 0.9 | 0.2, 4.3 |

Abbreviations: CI, confidence interval; OR, odds ratio.
[a] Adjusted for age, sex, education, race/ethnicity, smoking status, marital status, and income.

assessed the possible respiratory effects of the plume beyond Lower Manhattan and to have used a continuous measure of relative plume intensity, rather than binary residential location information, to infer exposures. Within the limitations of our data, we saw no associations of plume intensity with respiratory symptoms beyond Lower Manhattan.

Among residents who reported no previous diagnosis of asthma, there were no statistically significant associations between estimated plume intensities and new-onset or persistent cough/wheeze, using a plume intensity cutpoint of the 75th percentile (Table 2) or higher or lower cutpoints of the 50th, 60th, 70th, 80th, or 90th and 95th percentiles (see Appendix Table 1 and Appendix Table 2). Among residents who reported a previous diagnosis of asthma, there was no statistically significant association between estimated plume intensities and self-reported worsening of asthma symptoms or nonroutine medical care for asthma. There were too few asthmatics in the sample to conduct additional reliable sensitivity analyses with higher exposure cutpoints.

Previous studies using binary exposure metrics based principally on residential location found associations between living near Ground Zero and higher risk of respiratory symptoms. In 2 studies (12, 13), investigators compared exposed subjects who resided in apartment buildings within 1.5 km of Ground Zero with unexposed subjects living in apartments at least 9 km from Ground Zero and north of the site. Among previously asymptomatic persons, Reibman et al. (13) found consistent and statistically significant elevations in levels of respiratory symptoms, with greater persistence, and increased use of respiratory medications among persons living in the exposed areas as compared with those living in unexposed areas, but no differences in spirometry test results. For example, they reported elevated crude incidence ratios for a number of new-onset respiratory symptoms among previously asymptomatic residents, including ''any cough without cold'' (incidence ratio = 3.36, 95% CI: 2.38, 4.74) and wheeze (incidence ratio = 4.32, 95% CI: 2.68, 6.98). Among these subjects, Lin et al. (12) found elevated levels of new-onset upper respiratory symptoms, unplanned medical visits for respiratory problems, and respiratory medication use in exposed persons (12). Limitations of these studies included response rates less than 25%, the use of geographic location as the determinant of exposure, and possible reporting bias.

To assess the consistency of our results with those from previous studies, we compared responses among residents of Manhattan living at or below 14th Street (about 3 km north of Ground Zero), which includes persons living in the area engulfed by the more intense event-related cloud of dust and debris created by the WTC collapse, with responses among persons living above 14th Street (Table 3). We found that among nonasthmatics, residents living at or below 14th Street had statistically significantly increased crude and adjusted odds of reporting new-onset cough/wheeze and persistent new-onset cough/wheeze compared with residents living above 14th Street, which is similar to results reported in the other studies. Our smaller risk estimate may be due to smaller differences in exposure between Manhattan populations living above and below 14th Street, as compared with differences in exposure between the exposed and comparison locations studied by Reibman et al. (13). This is supported by our additional sensitivity analyses, which showed statistically significant results in our Manhattan-only analyses only using higher exposure cutpoints (90th and 95th percentiles).

In contrast to other studies of asthmatics (10, 11), among asthmatics we found no statistically significant increase in self-reported worsening or nonroutine asthma care when comparing residents of Lower and Upper Manhattan (Table 3). Because of the nature of the asthma severity survey question, which assessed post-9/11 asthma severity in the 4 weeks prior to the survey (several months after 9/11), we could not identify subjects who may have had acute exacerbations of asthma that were resolved prior to the question's time frame. Finally, asthmatics who were most affected by their exposure may have been underrepresented among participants because of the large numbers of Lower Manhattan residents who relocated and had not returned as of June 2002, when the survey was conducted (16).

### Strengths and limitations

A strength of our study is that we assigned relative plume intensities to individuals based on the results of sophisticated atmospheric dispersion modeling, which we believe was more accurate than assigning exposures based on residence in broad geographic areas or distance from Ground Zero. Observations and models indicated that the cumulative plume intensities were neither evenly distributed within geographic areas nor closely correlated with distance from the WTC. Furthermore, modeled plume intensities were less likely than proximity to the WTC to be associated with self-identification as exposed or not exposed, thereby reducing the likelihood of biased recall of symptoms after 9/11.

In general, analysis of health outcomes in communities exposed to air contaminants related to the WTC collapse has been hampered by the lack of ''real-time'' exposure data and limited outcome data. We based our estimates of relative ground-level plume intensities on the dispersion properties of a generic fine particulate aerosol. We calibrated these estimates using satellite images and actual air monitoring data collected at 4 stations close to the WTC. Despite these efforts, possible explanations for the lack of association with respiratory symptoms include misclassification of exposure. The relative estimates of exposure did not account for changes in chemical and physical characteristics of air contaminants, which occurred over time following the building collapse. We limited our analysis to the 5-day period immediately following the collapse, because modeled concentrations after that time period made a negligible contribution to cumulative exposure at any location. The location of survey participants was based on residential address. We did not have work location or any type of time-activity data with which to link the locations of estimated particulate matter concentrations with the locations of individual subjects over time. In addition, large numbers of residents in the vicinity of the WTC were displaced and therefore not captured by the survey. Some of these displaced residents, who may have had high initial exposures to the plume, were likely to be residing at other locations in the survey area at the time

of the survey. Finally, cumulative exposure may be less biologically relevant than peak exposure for the respiratory outcomes in this study, and we did not evaluate sensitive subpopulations, including children with asthma and the elderly.

### Conclusions

We found no strong associations between estimated 5-day cumulative residential WTC plume intensity beyond the immediate vicinity of the WTC and new-onset respiratory symptoms in nonasthmatics, or worsening asthma in asthmatics, on the basis of community survey data. The estimated residential plume intensities based on our dispersion modeling were the best available exposure estimates, but differential or nondifferential exposure misclassification might have biased the results towards our null findings. This study highlights the need for a rapid epidemiologic and environmental response capability to immediately follow up after other such events (terrorist-driven or not), to improve our understanding of the immediate and longer-term exposure hazards of these events and their possible health effects.

## ACKNOWLEDGMENTS

Author affiliations: Department of Environmental and Occupational Medicine, University of Medicine and Dentistry of New Jersey–Robert Wood Johnson Medical School, Piscataway, New Jersey (Robert J. Laumbach, Gerald Harris, Howard Matthew Kipen, Panos Georgopoulos, Pamela Shade, Sastry S. Isukapalli, Daniel Wartenberg); Center for Global Health and Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, Michigan (Sandro Galea); and New York Academy of Medicine, New York, New York (David Vlahov).

This study was supported by the National Institute of Environmental Health Sciences (grants K08 ES013520 and ES005022) and the Centers for Disease Control and Prevention (grant 1 U19 EH000102).

The authors thank Dr. Thomas Matte for providing valuable ideas and comments from study conception through manuscript preparation and for his contributions to the design and execution of the community survey.

Conflict of interest: none declared.

## REFERENCES

1. Landrigan PJ, Lioy PJ, Thurston G, et al. Health and environmental consequences of the World Trade Center disaster. *Environ Health Perspect.* 2004;112(6):731–739.
2. Lioy PJ, Georgopoulos P. The anatomy of the exposures that occurred around the World Trade Center site: 9/11 and beyond. *Ann N Y Acad Sci.* 2006;1076:54–79.
3. Stenchikov G, Lahoti N, Diner DJ, et al. Multiscale plume transport from the collapse of the World Trade Center on September 11, 2001. *Environ Fluid Mech.* 2006;6(5): 425–450.
4. Wolff MS, Teitelbaum SL, Lioy PJ, et al. Exposures among pregnant women near the World Trade Center site on 11 September 2001. *Environ Health Perspect.* 2005;113(6): 739–748.
5. Banauch GI, Dhala A, Prezant DJ. Pulmonary disease in rescue workers at the World Trade Center site. *Curr Opin Pulm Med.* 2005;11(2):160–168.
6. Banauch GI, Hall C, Weiden M, et al. Pulmonary function after exposure to the World Trade Center collapse in the New York City Fire Department. *Am J Respir Crit Care Med.* 2006; 174(3):312–319.
7. Izbicki G, Chavko R, Banauch GI, et al. World Trade Center ''sarcoid-like'' granulomatous pulmonary disease in New York City Fire Department rescue workers. *Chest*. 2007;131(5): 1414–1423.
8. Herbert R, Moline J, Skloot G, et al. The World Trade Center disaster and the health of workers: five-year assessment of a unique medical screening program. *Environ Health Perspect.* 2006;114(12):1853–1858.
9. From the Centers for Disease Control and Prevention. Self-reported increase in asthma severity after the September 11 attacks on the World Trade Center—Manhattan, New York, 2001. *JAMA*. 2002;288(12):1466–1467.
10. Szema AM, Khedkar M, Maloney PF, et al. Clinical deterioration in pediatric asthmatic patients after September 11, 2001. *J Allergy Clin Immunol.* 2004;113(3):420–426.
11. Wagner VL, Radigan MS, Roohan PJ, et al. Asthma in Medicaid managed care enrollees residing in New York City: results from a post-World Trade Center disaster survey. *J Urban Health*. 2005;82(1):76–89.
12. Lin S, Reibman J, Bowers JA, et al. Upper respiratory symptoms and other health effects among residents living near the World Trade Center site after September 11, 2001. *Am J Epidemiol.* 2005;162(6):499–507.
13. Reibman J, Lin S, Hwang SA, et al. The World Trade Center Residents' Respiratory Health Study: new-onset respiratory symptoms and pulmonary function. *Environ Health Perspect.* 2005;113(4):406–411.
14. Galea S, Vlahov D, Resnick H, et al. Trends of probable post-traumatic stress disorder in New York City after the September 11 terrorist attacks. *Am J Epidemiol.* 2003;158(6): 514–524.
15. Fagan J, Galea S, Ahern J, et al. Relationship of self-reported asthma severity and urgent health care utilization to psychological sequelae of the September 11, 2001 terrorist attacks on the World Trade Center among New York City area residents. *Psychosom Med.* 2003;65(6):993–996.
16. Vlahov DG, Galea S. Invited commentary: considering bias in the assessment of respiratory symptoms among residents of Lower Manhattan following the events of September 11, 2001. *Am J Epidemiol.* 2005;162(6):508–510.

**(Appendix Tables 1 and 2 Follow)**

**Appendix Table 1.** Incidence of Wheeze/Cough and Worsening of Asthma Symptoms by Quartile of Cumulative Exposure to the World Trade Center Plume (Excluding Lower Manhattan), Spring 2002

| Outcome and Quartile | No. of Subjects[a] | Case % | Crude OR | 95% CI | Adjusted OR | 95% CI |
|---|---|---|---|---|---|---|
| Nonasthmatics | | | | | | |
| New-onset symptoms | | | | | | |
| First | 431 | 12.0 | 1.0 | | 1.0 | |
| Second | 354 | 15.8 | 1.4 | 0.8, 2.3 | 1.5 | 0.9, 2.5 |
| Third | 347 | 12.2 | 1.0 | 0.6, 1.7 | 1.1 | 0.6, 1.8 |
| Fourth | 414 | 16.1 | 1.4 | 0.9, 2.3 | 1.2 | 0.7, 2.1 |
| Persistent new-onset symptoms | | | | | | |
| First | 430 | 4.2 | 1.0 | | 1.0 | |
| Second | 354 | 5.4 | 1.3 | 0.6, 2.9 | 1.5 | 0.6, 3.6 |
| Third | 346 | 4.5 | 1.1 | 0.5, 2.4 | 1.4 | 0.6, 3.4 |
| Fourth | 411 | 5.6 | 1.4 | 0.6, 3.0 | 1.4 | 0.6, 3.5 |
| Asthmatics | | | | | | |
| Worse symptoms | | | | | | |
| First | 62 | 11.9 | 1.0 | | 1.0 | |
| Second | 44 | 11.6 | 1.0 | 0.3, 3.5 | 0.9 | 0.1, 5.1 |
| Third | 56 | 26.4 | 2.6 | 0.8, 8.4 | 3.3 | 0.8, 13.4 |
| Fourth | 66 | 14.0 | 1.2 | 0.4, 3.9 | 1.5 | 0.3, 6.8 |
| Nonroutine asthma care | | | | | | |
| First | 63 | 24.6 | 1.0 | | 1.0 | |
| Second | 44 | 41.0 | 2.1 | 0.8, 5.7 | 1.9 | 0.6, 6.0 |
| Third | 57 | 40.3 | 2.1 | 0.8, 5.2 | 2.5 | 0.9, 7.4 |
| Fourth | 66 | 25.1 | 1.0 | 0.4, 2.6 | 0.9 | 0.3, 3.0 |

Abbreviations: CI, confidence interval; OR, odds ratio.
[a] Unweighted.

**Appendix Table 2.** Incidence of Wheeze/Cough and Worsening of Asthma Symptoms Among Persons Residing in the Vicinity of the World Trade Center Collapse (Excluding Lower Manhattan) on September 11, 2001, by Exposure Location, Using Alternative Percentile Cutpoints, Spring 2002

| Outcome | Exposure Cutpoint, % | No. Exposed[a] | No. Unexposed[a] | Case % | | Crude OR | 95% CI | Adjusted OR | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Exposed | Unexposed | | | | |
| Nonasthmatics | | | | | | | | | |
| New-onset symptoms | | | | | | | | | |
| | 50 | 761 | 785 | 14.1 | 13.8 | 1.0 | 0.7, 1.5 | 0.9 | 0.6, 1.4 |
| | 60 | 623 | 923 | 15.4 | 13.1 | 1.2 | 0.8, 1.7 | 1.1 | 0.7, 1.6 |
| | 70 | 504 | 1,042 | 17.3 | 12.6 | 1.5 | 1.0, 2.1 | 1.3 | 0.8, 2.0 |
| | 75 | 414 | 1,132 | 16.1 | 13.3 | 1.3 | 0.8, 1.9 | 1.0 | 0.7, 1.7 |
| | 80 | 344 | 1,202 | 15.8 | 13.5 | 1.2 | 0.8, 1.8 | 1.0 | 0.6, 1.7 |
| | 90 | 95 | 1,451 | 13.8 | 14.0 | 1.0 | 0.5, 1.9 | 1.0 | 0.5, 2.0 |
| Persistent new-onset symptoms | | | | | | | | | |
| | 50 | 757 | 784 | 5.0 | 4.7 | 1.1 | 0.6, 1.9 | 1.2 | 0.6, 2.2 |
| | 60 | 619 | 922 | 5.5 | 4.5 | 1.3 | 0.7, 2.3 | 1.3 | 0.7, 2.5 |
| | 70 | 500 | 1,041 | 6.1 | 4.4 | 1.4 | 0.8, 2.6 | 1.4 | 0.7, 2.8 |
| | 75 | 411 | 1,130 | 5.6 | 4.6 | 1.2 | 0.6, 2.3 | 1.1 | 0.5, 2.3 |
| | 80 | 341 | 1,200 | 4.3 | 5.0 | 0.9 | 0.4, 1.7 | 0.7 | 0.3, 1.7 |
| | 90 | 95 | 1,446 | 5.0 | 4.9 | 1.0 | 0.4, 2.9 | 1.2 | 0.4, 3.6 |
| Asthmatics | | | | | | | | | |
| Worse symptoms | | | | | | | | | |
| | 50 | 122 | 106 | 20.3 | 11.8 | 1.9 | 0.8, 4.4 | 2.5 | 0.9, 6.9 |
| | 60 | 99 | 129 | 17.8 | 14.8 | 1.2 | 0.5, 2.8 | 1.2 | 0.4, 3.2 |
| | 70 | 82 | 146 | 17.7 | 15.2 | 1.2 | 0.5, 2.7 | 1.4 | 0.6, 3.7 |
| | 75 | 66 | 162 | 13.9 | 16.6 | 0.8 | 0.3, 2.0 | 1.0 | 0.3, 2.8 |
| | 80 | 53 | 175 | 12.2 | 16.9 | 0.7 | 0.2, 1.9 | 0.8 | 0.3, 2.6 |
| | 90 | 12 | 216 | 20.7 | 15.8 | 1.4 | 0.3, 7.1 | 1.2 | 0.1, 12.8 |
| Nonroutine asthma care | | | | | | | | | |
| | 50 | 123 | 107 | 32.9 | 32.5 | 1.0 | 0.5, 2.0 | 1.1 | 0.5, 2.4 |
| | 60 | 99 | 131 | 32.3 | 33.0 | 1.0 | 0.5, 1.9 | 1.0 | 0.4, 2.2 |
| | 70 | 82 | 148 | 27.8 | 34.9 | 0.7 | 0.4, 1.4 | 0.7 | 0.3, 1.6 |
| | 75 | 66 | 164 | 25.1 | 35.1 | 0.6 | 0.3, 1.3 | 0.5 | 0.2, 1.4 |
| | 80 | 53 | 177 | 24.4 | 34.7 | 0.6 | 0.3, 1.3 | 0.7 | 0.3, 1.8 |
| | 90 | 12 | 218 | 19.3 | 33.4 | 0.5 | 0.1, 1.9 | 0.9 | 0.2, 5.1 |

Abbreviations: CI, confidence interval; OR, odds ratio.
[a] Unweighted.